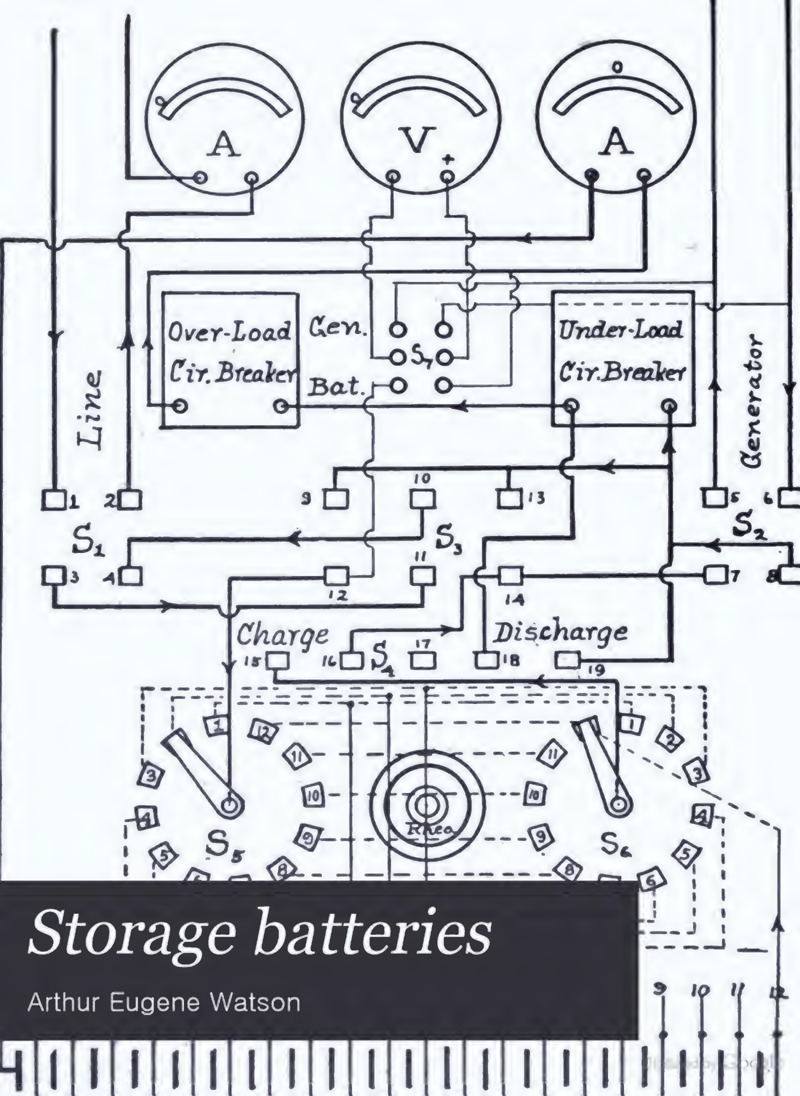

Storage batteries

Arthur Eugene Watson

STORAGE BATTERIES

Their Theory, Construction and Use

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STORAGE BATTERIES

CHAPTER I

STORAGE BATTERIES, — WHAT ARE THEY?

A STORAGE battery does not store electricity. It is a device for storing chemical energy by the action of an electric current. Of course, the additional qualifications are inferred, that the storage can be maintained for an indefinite time, and at will, under favorable conditions, this chemical change may be allowed to undo itself and return, as it were, the very current that produced it.

A crude illustration of a storage of energy may be seen in a stick of wood. Energy has been expended in producing it, and until used, the energy is in the potential form, that is, it is ready and willing to do work. When the stick is used for fuel, the energy becomes manifest in the form of heat, and in the language of the physicist, it is now kinetic. If now, from the ashes, smoke and gases, and with an expenditure of energy just equivalent to the heat given out in burning, the stick be reconstructed, an artificial storage of energy would have been made. Except for the very slow burning, called rot or decay, the storage could be again conceived as of indefinite duration.

An electric storage battery must then consist of such materials as are electrical conductors, and which will experience no change except when the current is flowing. These two requirements narrow the list of available materials to really a solitary few, but the added qualifications of having such materials as are cheap and easily manufactured are happily combined. Were gold and platinum, or silver and mercury, the only materials that could be used, no great commercial applications of storage batteries might be possible. Those actually found to operate the best, *i.e.*, lead and sulphuric acid, are plentiful and reasonably cheap. Some other constructions have been exploited, principally the lead-zinc couple in an acid solution, and the iron-nickel in an alkaline, and some mention of their peculiarities will be included in a later portion of the book, but the principal object is first to give a comprehensive yet brief treatment of the sort first mentioned.

Originally regarded as a laboratory curiosity, the storage battery has won its way into such favor that in company with its next of kin, the dynamo, it has almost entirely supplanted the primary battery. The essential difference between these two forms of batteries may be comprised under the statement that the former is regularly and readily restored to original and full working condition by a current of electricity, the latter is not. The zinc pencil or sheet, once dissolved, is quite beyond the reach of an electric current for its practical reproduction. In a limited sense, however, the operation of a

storage battery can be illustrated by the direct and reversed action of an ordinary gravity battery. Such a cell consists, as is well known, of a jar containing a sheet copper electrode at the bottom, covered with the blue sulphate of copper crystals, and a zinc casting at the top. After being in operation for a while, the aqueous solution separates into two readily distinguishable parts, that at the top being clear, yet saturated with zinc sulphate, that at the bottom blue, due to the copper sulphate. Although the latter is heavier than the other, the two will readily mix unless the current is always allowed to flow. In the normal operation of the cell, some of the sulphuric acid that was originally added acts upon the zinc, forms sulphate of zinc and liberates hydrogen; this hydrogen wanders into the copper sulphate solution, and displaces copper, — allowing it to be deposited upon the electrode, — and reproduces an equivalent amount of acid. The procedure is clearly shown by the equations:

$$\underset{\text{Zinc}}{Zn} + \underset{\text{Sulphuric Acid}}{H_2SO_4} = \underset{\text{Zinc Sulphate}}{ZnSO_4} + \underset{\text{Hydrogen}}{2H}$$

$$\underset{\text{Copper Sulphate}}{CuSO_4} + \underset{\text{Hydrogen}}{2H} = \underset{\text{Copper}}{Cu} + \underset{\text{Sulphuric Acid}}{H_2SO_4}$$

It is therefore seen that there is neither a gain nor loss of acid, but the continual presence of zinc and copper sulphate is necessary to permit this exchange, with the result of getting a current of electricity. It is well known that to maintain the current, these two substances must be regularly added.

If current from some other source be now sent backwards through such a cell, metallic zinc will be deposited out of the sulphate solution onto the casting; copper will be dissolved to form the blue solution, and apparently restore the cell to its primitive condition. This form of storage battery has actually been tried, but is defective by virtue of the difficulty and expense of getting chemically pure zinc, and the storage qualities are vitiated by the fact, as before mentioned, that unless the current is allowed to flow, even if not wanted, the two solutions will mix. As soon as the copper solution reaches the zinc, ruinous local action sets in.

These serious defects are not present with lead plates; this metal is cheaper than zinc, and is readily freed from all detrimental impurities, and in pure sulphuric acid of proper strength, the salts and oxides that are formed are quite insoluble, — a crucial condition of storage power; for, by whatever amount the chemicals or solutions will change their condition during periods of rest, the cell will have failed to fulfil its storage function. The use of sulphuric acid, too, must be regarded as fortuitous, for aside from cheapness, it emits no dangerous or offensive fumes, as are common to most other strong acids.

Occasionally the question is asked if the storage battery will ever be perfected. Such an inquiry is rather indefinite, but the answer can readily be that it is already practically perfect. For certain it is, that judged by the same standards of excellence or reliability that pertain to machinery or other artificial constructions, the battery

stands at the head. The steam engine is regarded as nearly as perfect a mechanism as human hands and mind have produced, yet such a machine is heavy, needs occasional repairs, expert attendance, and is expensive. The boiler, too, that supplies the steam is a marvel of strength and performance, yet the storage battery returns far more of the energy put into it than does either of these two creations. In the early '80's when storage batteries were first tried, they were regarded as a sort of cisterns, that could be located in a cellar, or some inconvenient place, be charged when the owner felt like it, be indefinitely drawn from and yet last as long as the house they were in. This conception proved to be an expensive one, and brought an undeserved discredit upon the batteries. Just as soon as they were regarded as worthy of the same degree of supervision and examination as is given to machinery or other valuable property, they at once proved their intrinsic qualities. A steam boiler is supposed to be fired in an intelligent manner, the water level kept at a certain mean, leaks prevented or stopped, and the whole structure occasionally submitted to a general overhauling, inspection, and cleaning. To give proper returns, the storage battery must be treated in similar manner. It is a waste of energy to overcharge, too low a discharge is injurious, and short-circuits dangerous.

Again, perfection is always regarded as a comparative term. Anything human is always open to improvement, and improvement should be sought and expected in the

construction and working of most devices. The degree of perfection varies too, with the particular use to which a machine is put. A stationary engine, under cover, well protected from dust, and every working part subjected to the close scrutiny of an engineer, may run without serious expense for repairs for twenty, thirty, or even forty years. A locomotive engine operates under quite different and adverse conditions, requires frequent repairs, and may be short-lived, yet for its work it may be as near perfection as the other. So with the storage battery; one set of standards can be applied to the installations in stations, but quite a different set is needed for the more rigorous condition of traction work. Installed in light airy places, with containing vessels made of glass, or, if of other material, at least open at the top for ready inspection, the former type has developed into highly satisfactory service, but for automobile propulsion, or railway train lighting, there must always be the same insidious causes of deterioration that pertain to the rest of the equipment.

Aside from the actual construction of storage batteries, a great deal of technical skill has been acquired in designing or proportioning them to fulfil particular conditions. Like the power plant of every establishment, the working conditions are first carefully analyzed, then the size and number of the cells together with the proper rates and limits of charge and discharge are rigorously specified. Some of the simpler conditions pertaining to the predetermination of a storage battery installation will

be considered in a later chapter. With the succeeding years of experience considerable finesse has been attained in applying automatic control over the charge and discharge, and even to the maintenance of the proper specific gravity of the solution. A complete exposition of all these details will be quite beyond the reach of this handbook, but in later chapters further mention of them will be made.

CHAPTER II

HISTORY OF PLANTÉ AND FAURE TYPES OF PLATES

It was in 1860 that Gaston Planté made his first battery. It merely consisted of two sheet lead plates rolled together, but not in actual contact, separation being effected by strips of flannel, and the whole immersed in dilute sulphuric acid. By repeated charges and discharges, and in reversed directions, — primary batteries being the source of current, — the surface of the lead plates was penetrated to an appreciable distance, forming what is called the "active material." Feeble primary cells could then be used for days or weeks, slowly "charging" the lead plates, and then the accumulated energy might be used during a comparatively short time. A generation ago, dynamos were not common to laboratories, and this means of getting momentarily large currents was highly prized, and the batteries were often called "accumulators." Indeed, closely similar use now pertains to central stations, for the cells are charged at a moderate rate for ten or twelve hours, and then discharged at a correspondingly higher rate in two or three hours.

Planté's batteries were rather expensive to form; the source of current was so meager that a year's action was

usually necessary before the plates could be said to be in good working condition. Chemical theory and analysis showed that one of the plates, now called the negative, acquired a gray coating of soft spongy lead, while the other, the positive, became covered with black peroxide of lead, or, as it were, lead ashes. In 1881, Faure (pronounced like figure "four"), realizing the herculean task of the primary battery in producing these results, sought to anticipate them by artificially applying coatings of the common lead oxides — litharge and red lead — to the plates. These commercial materials, being formed by the action of air upon the melted metal, are fairly cheap. They can be moistened with dilute acid, and spread upon the plates; though resembling paste when wet, the oxides quickly harden like plaster of Paris. By this device Faure was able to produce effective batteries in about one quarter of the time required for the other construction.

Both Faure's and Planté's batteries were defective, (*a*) from the use of too slender terminals connecting with the plates, which were either too weak mechanically, or were too soon disintegrated by the charging current, (*b*) from the rotting of the flannel and consequent leakage between the plates, and (*c*) from the lack of free circulation of the acid.

Faure at once patented his construction in France and received a patent in the United States early in 1882. But Charles F. Brush of Cleveland, Ohio, the "Father of Arc Lighting," had also been experimenting upon storage batteries. He used not rolls of lead, but castings

or "grids," in which were deep grooves; these he filled with red lead, and formed them in the usual way. Though incidentally providing an accessible shape of the plates, and circulation of the acid, Brush's fundamental claim in his application for a patent was the artificial or "mechanical application of the oxides to the surface of the metal." Brush's application for a patent was filed about a month in advance of Faure's, but in consequence of the prior issue of the French patent the U. S. commissioner issued the home patent to him also. Brush at once instituted interference proceedings, with the result of long delay, but with the final decision in his favor and the seventeen years of the life of the patent then really dating from May, 1886. Meanwhile the Brush Company had been exploiting the use of the batteries for incandescent lighting, usually locating them in the customer's cellar, and trying to charge them during the daytime from arc dynamos, — the location bad, the maintenance almost impossible. Finally, the company sought to recuperate its unproductive expenditures by a "do-nothing" policy, but only to seek damages from infringers. While the use of storage batteries in Europe was making great progress, activity in the United States was almost stifled in lawsuits and injunctions.

At length, this intolerable condition was relieved by the organization of the Electric Storage Battery Company, of Philadelphia, and the acquirement by it of all the essential patents. In reality, this organization became a sort of monopoly, but its existence seemed the only means for

a practical working. For their specialty, this company placed on the market a type of plates made under a French process, in which chlorides of lead and zinc were involved, thereby giving rise to the trade name "Chloride" cells. In this process, a fine stream of melted lead was reduced to flakes or shreds by an air blast, and the metal thus finely divided was dissolved in nitric acid; by addition of hydrochloric acid the metal was then precipitated in the form of lead chloride; this was removed, washed, dried, and mixed with zinc chloride, and pressed into pellets about one inch square and five sixteenths of an inch thick. A small hole was left in the middle of each to allow for properly locating the pellets on round pins in an iron mold. The grid, consisting of a mixture of lead and about five per cent of antimony, was then cast around the assemblage. Of course, the zinc chloride then needed to be removed, and since this chemical is soluble in water, while the lead chloride is not, the plates were placed in soak. This removal was facilitated and the lead chloride changed to lead sulphate by using dilute sulphuric acid instead of mere water, and the interspersing of zinc plates between the lead grids. Finally, after thorough washing, the sulphate was changed to peroxide of lead or spongy lead, for positives or negatives, respectively, by action of the charging current from the dynamos. It is seen, therefore, that in the final condition of the plates, no chlorides were present, but that their employment was merely an ingenious device to secure porous active material. They

were, therefore, essentially pasted plates with unduly large pellets.

Rigorous use in central stations brought out the inherent defects in all forms of pasted positive plates, and led gradually to their abandonment. Planté's original form was resusticated and developed. The Planté plate seems never to have been patented, or, if so, the patent had long since expired, hence no hindrance was placed on the practical exploitation of this type by any of the otherwise unfringing companies. Mere increased weight was regarded as by no means unfavorable for stationary uses, but various processes, usually involving the action of weak nitric acid, were devised to hasten the forming of the active material. Though there is considerable difficulty in removing the last traces of this acid, manufacturers commonly employ such forming solutions, and with the aid of powerful dynamo currents, the action that Planté spread over a year of time has been reduced to three days.

For light weight batteries, Faure plates may still occasionally be used for both elements, but Planté positives and Faure negatives seem to give the most satisfactory results for general purposes. Planté negatives seem to be inferior to those of the other sort. Some description of the actual shape and construction of both kinds will be given in other chapters, but before discussing any details that may be peculiar to any one manufacturer, it may be well to consider some of the fundamental principles common to all batteries of the lead type

CHAPTER III

THE ACTION OF THE LEAD STORAGE BATTERY

Two identical plates of pure lead placed in a solution of sulphuric acid, common to both, will exhibit no difference of electrical potential; a slight amount of the lead will be changed to lead sulphate, but both plates will still be alike. If, however, a current of electricity is sent through from one to the other, the one by which the current arrives will be seen to acquire a dark color, almost black, while the other, by which the current leaves, will be apparently unchanged; but with the action continued long enough, and with other conditions favorable, this latter, the negative plate, would be found to have acquired a soft or spongy surface, — but still of metallic lead; the other would be recognized as black oxide or peroxide of lead, PbO_2. One important feature to observe would be that although the ohmic resistance of the solution was relatively low, considerable electromotive force was needed to maintain the flow of the current. The cause was due to the production of an electromotive force within the cell, and in the direction to oppose the current. Such a condition must be necessary to the storage of energy, for, just as in the case of storage of

energy by water, unless work is done against a pressure there will be no possibility of getting out energy in return. The amount of this electromotive force is, however, rather surprising; though low as compared with ordinary dynamo potentials, it exceeds that of any *primary* battery. From such couples as zinc and copper, zinc and carbon, the difference of potential may be greater than one, but less than two, volts. Between two similar plates of lead, no difference of potential at all was of course possible, but between lead peroxide on one and spongy lead on the other, the electromotive force is normally 2 volts, immediately after an ordinary charge 2.2, and after an extended one a momentary pressure of 2.5 volts. That is, between plates of the same metal in different physical conditions, a greater difference of electrical potential is found to exist than between two plates of different metals or elements.

Some difference of opinion exists among chemists as to changes that take place in a storage cell. Initial and final conditions are clear, but means of proving some of the intermediate steps are not available. The principal actions generally accepted are as follows:

During the Charge

The act of placing the metallic lead in the acid results, as just stated, in the formation of some lead sulphate. Indeed, too much sometimes forms, and is injurious to the battery, and this excess, called "sulphating," is to be avoided. As soon as the charging

current is introduced, sulphuric acid is decomposed. Modern theories of electrochemistry declare that the very act of diluting the acid with water has already partly "dissociated" the acid into its two component "ions" or "carriers," and that the electric current merely continues the separation. A technical expression would be that the acid is "electrolyzed,"—electrically analyzed, — the equation being

$$\underset{\text{Sulphuric acid}}{H_2SO_4} = \underset{\substack{\text{Hydrogen} \\ \text{with positive charge}}}{\overset{+}{2H}} + \underset{\substack{\text{Sulphuric oxide.} \\ \text{with negative charge}}}{\overset{-}{SO_4}} \qquad (1)$$

The hydrogen ion has acquired a positive charge and the rest of the substance one of negative sign. Since in electrical matters, unlike signs attract, the SO_4 at once travels *against* the current towards the positive plate, by which the current entered, while the hydrogen travels *with* the current to the negative plate.

At the Positive Plate

The SO_4, being rich in oxygen, has a powerful oxidizing influence, and in the presence of plenty of water produces the following effect upon the film of lead sulphate on the positive plate:

$$\underset{\text{Sulphate of lead}}{PbSO_4} + \underset{\text{Sulphuric oxide}}{SO_4} + \underset{\text{Water}}{2H_2O} = \underset{\text{Peroxide of lead}}{PbO_2} + \underset{\text{Sulphuric acid}}{2H_2SO_4} \qquad (2)$$

At the Negative Plate

Just as in the case of the reversed gravity cell described in Chapter I, the current causes the hydrogen to displace the metal in the layer of sulphate on this plate.

$$\underset{\text{Sulphate of lead}}{PbSO_4} + \underset{\text{Hydrogen}}{2H} = \underset{\text{Lead}}{Pb} + \underset{\text{Sulphuric acid}}{H_2SO_4} \qquad (3)$$

It is seen from equation (1) that one molecule of acid was lost, but from (2) that two were gained, and from (3) that one was gained, — a net gain of two for every one that was lost. This means that in the charge, sulphuric acid was actually produced, with the result of increasing the specific gravity of the solution. This is one of the most important factors in storage battery operation, since by use of the hydrometer, an instrument for measuring the specific gravity of liquid, a most accurate test can readily be made upon the condition of every cell. Indeed, in central station use, daily tests with this gauge are usually enforced.

Now, even though the charging current be stopped, there will still exist a difference of potential between the two plates. It will not be quite as high as the voltmeter indicated during the charge, for some pressure, .2 to .3 volt in actual cells, was needed to drive the current against the ohmic resistance of the liquid and plates. Further, the excess of hydrogen in the solution will leave the potential .2 volt above normal for a short time, or until some current has been taken out; 2.5 volts per cell during charging, 2.2 immediately at close of charg-

ing, and 2 volts for normal condition are the usual figures.

During the Discharge

When external electrical connection is made between the plates, a current is allowed to flow. The chemical changes are believed to be as follows:

At the Negative Plate

Sulphuric acid attacks the particles of spongy lead, forming sulphate of lead and liberating hydrogen.

$$\underset{\text{Lead}}{Pb} + \underset{\text{Sulphuric acid}}{H_2SO_4} = \underset{\text{Lead sulphate}}{PbSO_4} + \underset{\text{Hydrogen}}{2H} \qquad (4)$$

With their positive charge, the hydrogen ions now give direction to the current, and travel through the solution to the other plate, where the reaction may conveniently be described in two steps, the formation first of a lower oxide and then the sulphate.

$$\underset{\text{Lead peroxide}}{PbO_2} + \underset{\text{Hydrogen}}{2H} = \underset{\text{Lead oxide}}{PbO} + \underset{\text{Water}}{H_2O} \qquad (5)$$

$$\underset{\text{Lead oxide}}{PbO} + \underset{\text{Sulphuric acid}}{H_2SO_4} = \underset{\text{Lead sulphate}}{PbSO_4} + \underset{\text{Water}}{H_2O} \qquad (6)$$

Both plates are thus seen to tend to become alike, that is, to be both of lead sulphate, but as long as any spongy lead is left upon the one, and lead peroxide upon the other, a difference of potential of about 2 volts between them will be found. In consequence of the resistance of these active materials and the grids or

plates supporting them, and of the solution itself, some voltage will necessarily be wasted in driving the current through them, and the measured potential during discharge may be a little lower than this amount, but just as in the case of a steam boiler, it is not advisable to let it get entirely empty, so the storage cell should not be discharged below a certain minimum, say 1.8 volts. Below that point, the voltage falls off so rapidly as to be incapable of doing its assigned work, and the plates are liable to get covered with a layer of excess of lead sulphate that may be difficult to remove.

From the equations it will be seen that one part of sulphuric acid was used up at each of the plates, just offsetting the gain of two parts that was made during the charge. This loss of acid means, of course, a reduction in the specific gravity of the solution, a change readily detected on the hydrometer scale. In actual use, when a battery is fully charged, the specific gravity of liquid should not be above 1.21, nor when discharged, below 1.15. Stationary batteries with relatively large quantities of liquid can preserve the density well within these limits, but those for portable or vehicle use have so small space for the solution as to make the variation exceed this limit; in order not to pass too far below the lower limit, and introduce the danger of "sulphating," it is common practice to have the upper limit as high as 1.26.

The particular average density illustrates a peculiar and fortuitous property in conductivity of solutions. Pure water and concentrated sulphuric acid are believed

to be practically non-conductors, but different mixtures of the two possess varying degrees of conductivity; with the particular mixture, four or five parts of water to one of acid, that gives a density of 1.20, the resistance is the lowest, and the dangers of sulphating are the least.

For determining the condition or degree of charge of a storage battery the voltmeter alone is not a reliable instrument; it is indispensable in the switchboard operations, and will surely indicate abnormal and accidental conditions, but cannot readily detect variations and slight defects in individual cells. Certainly, if the battery is a fairly constant potential device, the voltmeter cannot be expected to find considerable or even readable variations in potential. The case is like that of a high water-tank or reservoir; this, too, is for maintaining a constant pressure, and an ordinary dial gauge could not be depended upon to give a reliable indication as to whether the reservoir was almost full or almost empty. If, suddenly, the gauge indicated zero, the place would be known to be empty, but that condition is of course to be avoided. A gauge floating on the water is a simple and reliable device, so the hydrometer floating in the battery acid is found to give a safe indication of the condition of the plates. In large plants daily observations are taken of every cell, and recorded on a chart. Water is added to replace that lost by evaporation or decomposition, and acid to replace that lost by spraying. If a cell shows an unexpected diminution in specific gravity, a fault is at once suspected and, if possible, it is located and removed.

CHAPTER IV

CONSTRUCTION OF THE PLATES

As might be expected, there is a great diversity in the forms of plates as produced by the different manufacturers, but there is no difficulty in classifying their characteristics or peculiarities under a comparatively few heads: (*a*) Whether of the Planté or Faure type of formation; (2) whether arranged to stand on their lower edges, or to hang from upper edges of jars, and (3) whether the supporting frame or "grid" does or does not form a constituent part of the active material. More explicit and incidental features can well be reserved for the chapters describing some of the present commercial forms of batteries.

In all, the aim is to give the largest possible area of surface of the active materials. Plain sheets of ordinary lead would be very uneconomical for the Planté form, but by rolling or cutting deep grooves in castings or thick plates, the area presented for action by the electrolyte is increased eight or ten times; or by coiling spirals of thin corrugated lead ribbon and pressing them into round holes in cast grids, the equivalent is produced. Such plates are readily made by any one, and cannot be

surpassed for long life and reliability. The grooved plates are necessarily made of soft and pure lead, and if positives, they will ultimately crumble into the black crystalline powder, lead peroxide. With the cast grid, however, for retaining the active spirals, about five per cent of antimony may be added; this other metal does not seem to be detrimental to the cell, but merely strengthens the grids, and protects them from direct action; in case the spirals become deteriorated new ones may be added.

While the lightest weight for a given output can be obtained from the Faure, or pasted plates, they ordinarily possess special weaknesses, the principal one being due to the forces of expansion. The cause of this was not at first recognized, but when the effects were discovered, means were sought to suppress it. Though it may occasionally be still possible to find some statement that an inventor claims to have made a plate so strong as to prevent expansion, a more reasonable attitude is to realize that the forces of expansion and contraction are practically irresistible, and to admit and even encourage their action. Light will be thrown on the situation by again referring to the equations in the preceding chapter. During the charge, lead sulphate, having a molecular weight of 302, changes to lead peroxide, with a molecular weight of 238. It is true, also, that weighing less the lead peroxide takes up less room than the sulphate; therefore, in the charge there is a shrinking in the size of the pellets or blocks of the active material. As the

lead grid that supports this active material is not elastic the pellet may become loose and fall out, even bridging across the narrow space and coming into contact with the negative plate. Again, on the discharge lead peroxide is changed to lead sulphate, and the pellet may be expected, therefore, to expand and just fill the space it formerly occupied, but if still in place the pellet may not be in good electrical contact with the grid, and since the repeated operations of charging and discharging more active material is constantly being formed, space for this extra amount can be found only by stretching the retaining walls. As the parts of the grids nearest the terminal connections are the most acted upon, and as exactly uniform mechanical strength cannot be given to all parts, the effects known as warping, bending, buckling, etc., are at once seen to be accounted for. One step toward eliminating these defects was to make a flexible plate of lattice work, imitating the freedom of coarse netting as was done originally by Bradbury and Stone, or by using antimonious lead grids so as to limit the supply of material for formation of the expansive materials. In actual use, positive plates that were originally $6\frac{1}{2}$ in. square have been known to grow to about $7\frac{1}{2}$ in. square. It is therefore seen that the cross bars that join successive negative plates must be high enough to prevent short-circuiting with the growing positives, and vessels should be large enough to cope with the old age of the plates rather than with their infancy. This increase of size and change of shape of the positive

grids have been the vital reasons for abandoning their use for all purposes where light weight is not imperative. The negatives suffer no such action, but tending more and more to the spongy metallic condition, really improve with age.

The third form of plates does not have the active material as an entity with the electrodes, but flat hard rubber, or earthenware receptacles, provided with numerous shelves containing the active material, are clamped against antimonious or pure lead plates. In such, the growth in quantity of the active material is expected to maintain a sufficient pressure between the parts to give good electrical contact. The "Hatch" storage cell is about the best representative of this class. In this construction, freedom of circulation of the electrolyte would seem to be impaired, and with high rates of discharge the acid in the neighborhood of the plates can readily be conceived as falling below the minimum practical limit. The point most urged by the makers of the Planté plates, with rolled or cut grooves in the pure lead, is that the active material is most surely in good electrical contact with the supporting and conducting structure, and that the parts of the plates most remote from the terminals are in essentially as active condition as those nearest. It is likely that cells of the Hatch type would be found better adapted for occasional and moderate use than for the rigorous conditions of central or sub-station work.

Some years ago various cells were described for ama-

teur or experimental use which had grids formed of alternate straight and corrugated lead ribbons soldered into a rectangular frame of stronger lead, and the interstices filled with red lead or litharge. To prevent falling out of the active material, sheets of asbestos or cellulose fiber were laid between the plates. Such a construction is now seen to be faulty in several important respects. Aside from the tediousness of the method of making the grids, there is (*a*) the undesirable addition of tin and perhaps other impurities in the solder used, (*b*) no provision for the inevitable increase in size of the grids due to expansion, — the corrugated strips would allow extension, but not the straight members, — (*c*) prevention of free circulation of the acid, and (*d*) the formation of acetic acid from the woody fiber of the cellulose. Further, wooden containing vessels were prescribed, but though carefully made and smeared with all sorts of waterproof paints they are bound to leak; if so large as to preclude the possibility of use of glass, the wooden tanks must be lead lined, and the plates carefully supported on glass insulators. Glass jars should be used whenever possible, and placed high enough in a light place to allow ready and frequent inspection to be made.

The effect of the presence of impurities in the lead deserves more than passing attention. Sulphuric acid will act upon most metals, and by whatever amount these foreign elements are present, the acid will be permitted to form undesired compounds, and then, by the

presence of the lead, subsidiary ones in addition; the practical result is that such impurities will prevent a cell from holding its charge. Ordinary commercial lead, such as is sold in "pigs," is practically free from all injurious metals except silver, and the percentage of that may be so small as to be of no account in ordinary use. Still, most manufacturers aim to get chemically pure metal, and pay half a cent or more per pound for the desilverized quality. Platinum stands at the head of the list as being the most detrimental to the action of a battery, but fortunately there is little likelihood of any of this metal being present in the lead. Since the acid receives its final concentration for commercial use in platinum vessels, a small trace may possibly be conceived as existing in it. Such a contingency would be avoided by procuring the acid that had received only the working degree of concentration. At any rate, the pure acid, rather than the grade commonly used in foundry and bleaching work, must be insisted upon.

Usually there is one more negative than positive plate per cell. This is an important matter for ordinary use. For very small currents, however, such as might be employed in calibrating voltmeters or for some other precision measurements, it may be allowable to use mere "couples," but the aim must ordinarily be to have both sides of every positive plate equally acted upon, or disastrous buckling or warping will result. By letting the outer ones always be negatives, the unused surface is assigned to a plate that is subject to no such distortion;

some "sulphating" may be visible on these sides, but it is not to be interpreted as representing the real condition of the inner and active surfaces.

One effective means of preventing the danger of connection between the plates by accumulation of released active material in the bottom is to suspend them from the upper edges of the jar. Incidentally the sagging of the plates, due to their weight, then assists in keeping them straight. This procedure is imperative for large plates, and is being very largely adopted for those of small or ordinary size.

CHAPTER V

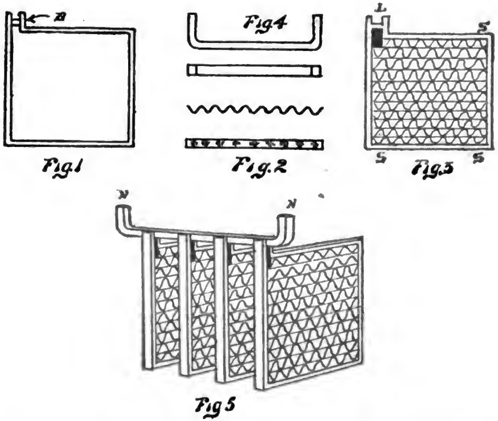
HOW TO MAKE A STORAGE BATTERY

In properly proportioned cells, the capacity is directly proportional to the number and size of the positive plates. No fast rules can be given for determining the exact proper rate of charge and discharge, but the lower the rate the higher the efficiency, with a gain also in the life of the battery. A standard rating is to allow about 25 square inches of positive plate per ampere. The two sides of a plate 6 in. x 6 in. would thus present 72 square inches of surface, and 3 amperes per plate would not be excessive. If a 10-ampere battery was wanted, 3 positives and 4 negatives per cell would probably suffice. The glass jars for holding them should be not less in outside dimensions than $6\frac{3}{8}$ in. x $7\frac{7}{8}$ in., and 10 in. in height. About 14 lb. of solution would be needed, and complete weight would be 50 lbs. In use, the cell should be capable of supplying a current of 9 to 10 amperes for eight hours; at higher rates of discharge, the ampere-hour rating would be somewhat less.

While there is no question that plates larger than this should be susoended from the upper edges of the jars,

this size may be allowed to stand upon glass ledges in the bottoms.

Almost any form will do for the grid of the negative plate, and while a cast-iron mold of somewhat complicated form would be advisable if several hundred plates



FIGS. 1–5.—Warwick Type of Home-made Battery Plates.

were to be made, for a few only, the Warwick type is more available. The construction is plainly seen from Figs. 1, 2, 3, 4 and 5. First, frames of $\frac{3}{8}$ in. x $\frac{1}{4}$ in. lead bar are bent around a wooden block 6 in. x 7 in. by $\frac{1}{2}$ in. thick, and a connecting piece of lead inserted, as shown in Fig. 1. As far as the builder is able he

should use "burning," or really melting of the metal together with the aid of a gas-jet rather than ordinary soldering. After the frames are secured, the interior space is to be filled, as shown in Fig. 3, with alternate straight and corrugated strips of $\frac{3}{8}$ in. x $\frac{1}{64}$ in. lead tape, shown in Fig. 2, — preferably of the desilverized quality. The ends should be attached by burning, and at indiscriminate points, the strips should be attached together. If solder is used, 'it must be of as poor quality as possible, — not the "half-and-half" grade, but having a very small proportion of tin. Resin is a much better flux for lead than ordinary soldering acid.

For the pasting process, the grid thus made is to be laid on a pane of glass; about a teacupful of the litharge in a shallow crockery dish is to be moistened with about half that quantity of acid and water in the proportion of one to five. Of course, it is understood that the solution is to be prepared beforehand, that the acid was poured very slowly into the water, say in an earthenware crock, and has become thoroughly cold. A small trowel is about the most suitable implement to use for the stirring and pasting, and the real amount of iron that is gotten into the filling seems to be inappreciable. Some heat will be evolved at the mixing, and though an insufficient amount of liquid might at first seem to have been taken, the stirring or mixing will as often prove that too much was used. A little practice will indicate about the right proportions. The materials set quickly, like plaster of Paris, so no waiting is to be tolerated,

and only enough for one side of a plate is to be mixed at a time. When pressed full, the grid is to be slid off the glass plate, and the other side similarly treated, and then the now fully pasted grid placed edgewise in a rack to dry.

The meager quantity of acid used for mixing the paste has not necessarily resulted in a complete chemical action upon the litharge, and were the plates now to be finally immersed in the working solution, considerable heat, with evolution of hydrogen and dislodgment of the filling, would be experienced. This action can be fore-stalled by momentary daily immersion or dipping the plates into a vessel of the solution. However quickly this wetting may have been done, there will be, on the first day, considerable sizzling, on the next day less, and so on until all evidence of action disappears. Four such plates may now be fastened together as shown in Fig. 5, by using three pieces of 1-in. board as separators, temporarily holding them in place with string; the cross bar is of $\frac{3}{8}$ in. x $\frac{1}{4}$ in. lead, as shown in Fig. 4, but it will be an improvement to have the ends marked *N* four or five inches longer than shown, say at least 10 in. long in all, so as to bring the connections well out of reach of the spraying of the acid.

For a cast grid there is no doubt but the form originally devised by Correns in Germany and modified in this country by Bradbury and Stone of Lowell, Mass., and now adopted by the Electric Storage Battery Company in place of their original "Chloride" type, is the

best. The author, too, has copied it, and used it in very effective batteries. The particular dimensions used were $6\frac{3}{8}$ in. x 8 in., by $\frac{5}{16}$ in. thick. A view of a complete grid is given in Fig. 6, showing face and vertical sectional views. Up and down, there are continuous strips, needful for the unimpeded flow of the metal during the casting process, but the horizontal members are interrupted; it will be seen, therefore, that lateral expansion is allowed, for the vertical members will become wavy or corrugated instead of straight. Positive plates made with these grids will last for years, negatives indefinitely. The filling, instead of being broken into independent pellets, is seen to consist of a continuous strip, extending from top to bottom, under and over the successive cross bars, and for ordinary use is securely locked in position. For these grids the author has used only pure lead, and to get good castings the metal must be poured at a red heat, and at least one casting a minute made, or the mold will get too cool.

The mold itself is rather difficult to make, but consists of two identical iron castings, with inner elevations and depressions fitting together. A section taken through the place where a vertical row of holes would be is shown in Fig. 7. The metal runs down the vertical rows, and flows sidewise into the triangular openings in the summits of the projections.

For joining four such grids together, one of the lead castings shown in Fig. 8 may be used. Upper ends of grids pass through the rectangular openings, and are

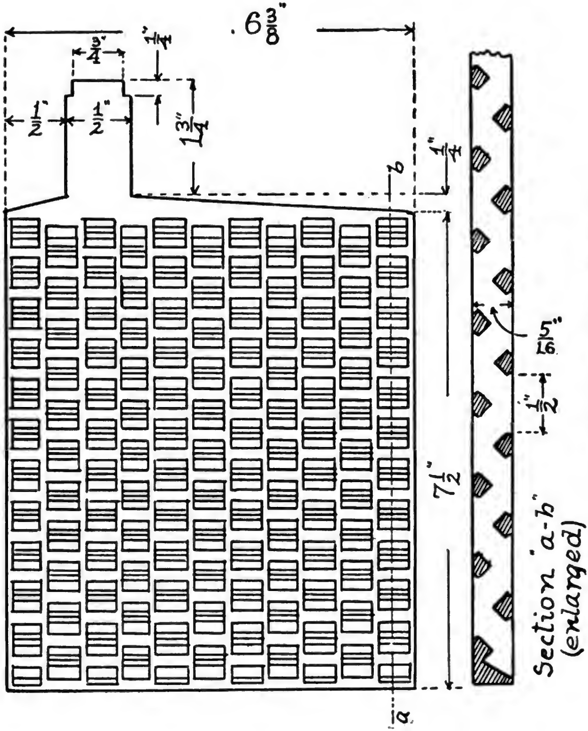


FIG. 6. — Bradbury-Stone Lattice Work Grid.

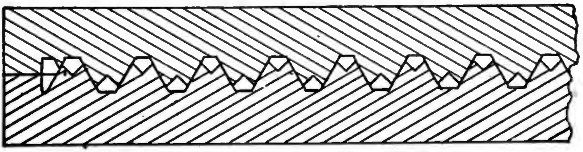


FIG. 7.—Section Showing Construction of Mold for Casting Lattice Grid.

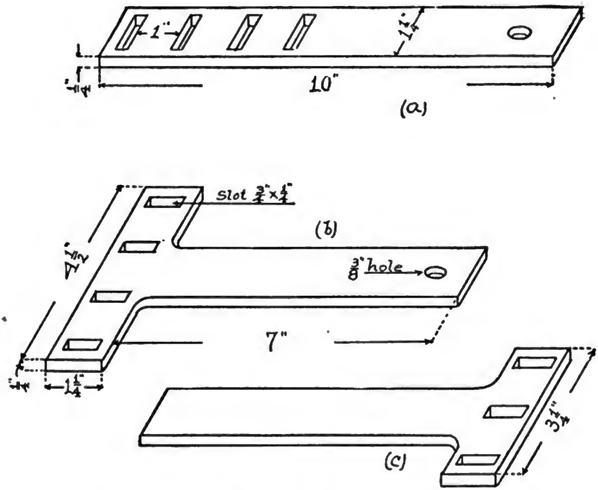


FIG. 8.—Common Shapes of Cross Bars for Small Battery Plates.

there soldered or burned together. If similar grids are to be used as positives, the only difference to observe is that red lead (minion) rather than litharge makes the more appropriate paste. Either kind may really be used for both plates, but the selection usually made allows more economy in the forming process.

If the Planté formation is to be adopted for the positives, and the builder has access to a small metal planer or shaping machine, the method very successfully used by the author may be followed. Slabs of lead can be cast, with dimensions as given in Fig. 9, but the rolled metal is denser and more readily cut with the necessary grooves. Some economy of material may be gained by getting the rolled sheets large enough to make two plates and cutting them with a coarse wood saw. Take first the longer crosswise cuts, then pry one of the cuts open far enough to insert the end of a keyhole saw, to take a lengthwise cut. To fasten the plates on the planer bed needs some special knife-edged strips, attached crosswise, and pressing into the longer edges of the slabs. A suggestion is given in Fig. 10, but the builder may substitute his own ingenuity. In this view is also shown a roller attached to a somewhat flexible arm, say to a piece of $\frac{3}{8}$ in. x $\frac{1}{4}$ in. soft steel bar, which in turn is clamped under a screw in the fixed part of the planer head. The pressure upon the lead plate can be adjusted by moving the whole head, and thereby not interfere with the setting of the cutting tool itself. The shape of this latter is also shown in the cut, but its action can be

described as like that for cutting a flat sheet of paper with a pen knife, — the blade must not be perpendicular to the paper, nor must the point go ahead, but a very

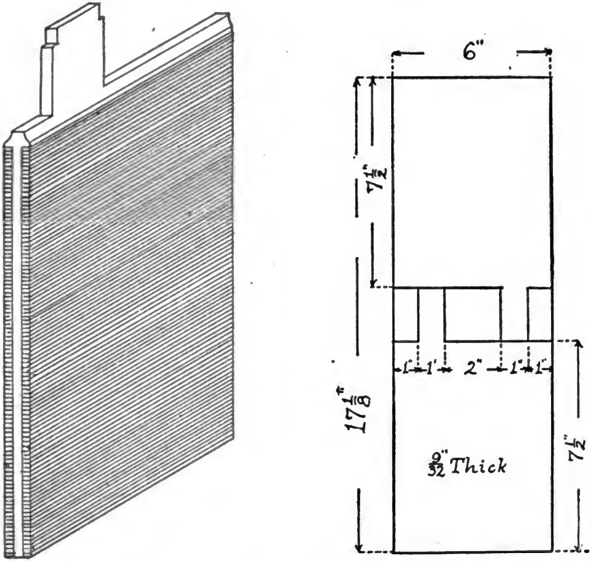


FIG. 9. — Grooved Lead Slab for Planté Formed Plate.

slanting cut must be taken, or the paper will be torn instead of cut. Of course no metal is to be removed, but the surface of the plate increased like that of a

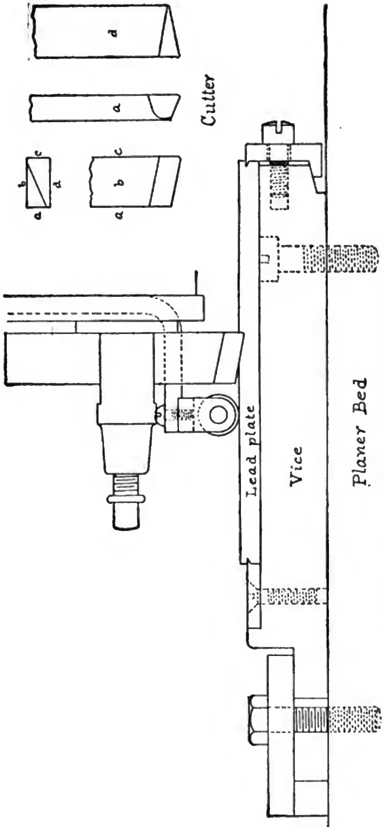


Fig. 10. — Planer Fixture for Grooving Plates.

plowed field. If the knife be held not only slanting, but tipped sidewise, it will still more nearly represent the shape of the cutting edge. The whole tool may be inclined one way or the other in the tool post, to give the most satisfactory sort of cut. With the bottom edge of plate nearest to the person, the cuts should begin at that place, and with a spacing of about fourteen to the inch, continue to within about $\frac{1}{4}$ in. of the upper edge, this stock being preserved for stiffening the plate. Most of the plates made by the author have the cuts taken vertically, with an uncut strip left across the upper edge; this method is preferable and can be adopted if the planer will stop in closely the same position at the end of each cut, and if the tool does not tear the stock in withdrawing from the cuts. Special care must be taken with the final cuts on the second side, for then the roller will probably have passed off and the plate is the most weakened. About an eighth of an inch of uncut metal should intervene between the two groovings. The tool really enters the lead but little over a sixteenth of an inch, but in consequence of the slanting character of the cut, a swath about an eighth of an inch is turned up, and the plate that was originally $\frac{9}{32}$ in. thick may finally be about $\frac{7}{16}$ in.

Three such plates can be joined to a cross-bar similar to that used with the negatives as given in Fig. 8, taking care that the long end must extend to the right with half the cells, and to the left with the others. With the **T** shape of cross-bar, shown also in Fig. 8, the necessity

of observing rights and lefts would be obviated, but when in place and connected the cells would occupy a little more space, and the flat surface rather than the edges of the plates would be visible.

Six sheets of perforated hard rubber, $\frac{1}{32}$ in. thick and of the size of the negative plates, are to be provided, and when the seven plates for a cell are slipped together these insulating septums are to be inserted, then strips of wood, $\frac{1}{4}$ in. square and 8 in. long, three in each of the six spaces, are to be thrust in vertically, and pressing the hard rubber against the negatives. The whole structure can be bound with strong cord, for preventing dislocation during the transference to the jar. If the latter has ledges in the bottom, well and good, but if not, substitutes must be provided; these can be made from solid glass rod, $\frac{3}{8}$ in. or $\frac{1}{2}$ in. in diameter, set into wooden blocks that are cut to fit the bulging shape of the bottom. The idea is clearly seen in Fig. 11.

An old method of trying to hold the plates together was by the use of strong soft rubber bands, but these are expensive, and short-lived. A very satisfactory method is to use two lead bands of stock $\frac{1}{2}$ in. x $\frac{1}{8}$ in. Across the edges of the plates, sheet hard rubber separators, notched at the ends to receive the bands, are used, but elsewhere the lead bands rest directly against the negative plates. After bending these bands closely in the shape required, the ends are lapped about an inch, in the middle of one of the negative plates, a piece of cast iron laid on each side, and the metal burned together.

Removal of these bands is very seldom necessary, but if required, they can be stretched sufficiently to slide off. They are much stronger than rubber and being in contact with the negative rather than the positive plates suffer no deterioration, and yet will stretch to accommodate any amount of expansion. One band can be

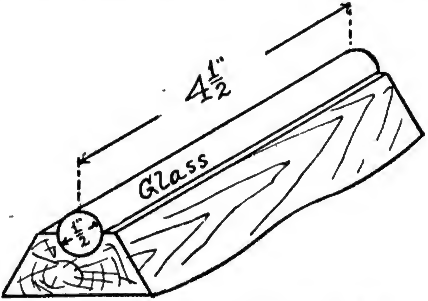


FIG. 11. — Bottom Support for Small Plates.

about two inches from the bottom, the other about as far from the top.

If the builder wishes to avail himself of the advantages of the suspended type of plates, he can do so by burning hooks onto the rolled lead plates,. or by providing for them in the molds for the cast grids.

For some uses, such as in calibrating voltmeters, determination of insulation resistance, etc., several hundred volts, but only small currents, may be needed. A large number of quite small cells are therefore

joined in series, each one of which may have only a single positive and negative plate. Such cells are often called "couples." This construction still is allowable, indeed, for some purposes where several amperes are needed, but in consequence of only one side of the plates being acted upon, they will be sub-

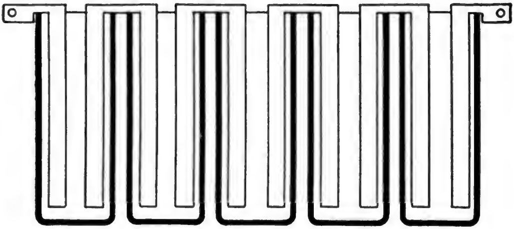


FIG. 12. — Group of Simple Elements made from Ordinary Sheet Lead.

ject to buckling or warping, just as a board wet on one side only.

A simple construction of cells that may still be called couples, yet not so subject to this drawback, and therefore sufficient for extended use for practical purposes, is shown in Fig. 12. The particular size may be subject to the builder's wishes and to the material he may have on hand. Five cells are shown, and extending from each one into the next are strips of ordinary sheet lead, such as is used for roofing purposes. In Fig. 13 a method of marking out the

strip is shown, that clearly avoids much loss of material. Some of the cuts can be made with shears, the others are out of reach, but these can be readily made with a sharp 1-in. "framing" chisel. With the lead strip on a hard-wood block, a few hours work will produce

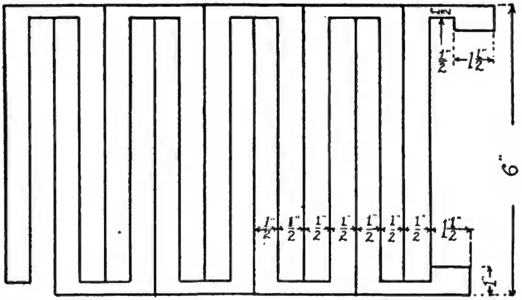


FIG. 13. — Economical Method of Cutting the Sheet Lead for Battery shown in Fig. 12.

several hundred of these square-cornered U's. End pieces should be a little different from those composing the main body of the cells, and their construction also is clearly shown.

Square or rectangular glass jars are to be used, and quite a number of the strips are to be put in each, the capacity in current being directly proportional to the total area presented for action by the electrolyte. Some clearance for circulation of the solution is imperative, also for the growth in thickness of the positive

plates, so that perhaps about one-half the maximum number that could be squeezed in would be a good limit. No clamping together of any except the terminal groups will be necessary, and these can be sufficiently well joined by use of a lead rod hammered over at the ends; or, the outer edges of the plates may be soldered to a common lead strip that will give an end far enough removed from spraying of the acid to permit attaching a copper wire.

If square glass jars are not available, a skillful experimenter may be able to substitute square bottles, from which he has cut the tops. To do this two methods are commonly known. One is to make a notch with a file in the glass where the cut is to be started, then to follow around slowly and carefully with an almost red-hot poker or soldering copper. Sometimes the crack will proceed where it is wanted, but too often, due perhaps to the varying quality of the glass or to its unequal thickness, the results are exasperating. The other method is to tie a cotton string, soaked in kerosene, around the top of the bottle, where the separation is desired, then light the string. When nearly burned out, suddenly thrust the whole end of the bottle into a vessel of cold water. In either case the sharp edges of the glass should be removed by filing or grinding.

This construction of storage cells is about the simplest that can be devised, but will be found highly effective. In consequence of the plates not touching

the bottom of the jars, they run little danger of internal short-circuiting through contact with the "mud" that inevitably collects there.

Twenty or more strips could readily be used with jars 2-in. square and 6-in. deep, inside measurements, and give a capacity of 3 to 4 amperes. Slow rates of charge for a few cells could be provided by permanently connecting them to gravity batteries, using three of the latter to every one of the storage type. If a direct current is at hand from the regular lighting circuit, a few cells could be connected into the cord leading to some lamp that was considerably used. The light would be somewhat lessened, but the cost of charging the cells would not be noticed. For cells of this type, being plainly of the Planté sort, some patience and time will be necessary to get the lead into the condition in which it will have the desired capacity for holding a considerable charge. Repeated chargings, and that, too, in reversed directions, are required.

CHAPTER VI

SETTING UP A STORAGE BATTERY

MANUFACTURERS of the Planté plates employ special forming solutions, usually involving the use of very dilute nitric acid. Special precautions are needed finally to eliminate this acid. In this chapter it will be assumed that the user has the plates ready formed, or intends to form them in the solution in which they are to be regularly used.

In a purchased set of plates the negatives are usually marked *N* on the end of the terminal lug, but they can otherwise be recognized by their grayish color, and by the fact that, unless it be a laboratory couple, for very small currents, there will be one more plate in the negative group than in the positive group or those with the dark brown color. As there is sure to be some spraying and spilling of the acid, the cells should not be placed directly upon the benches, but upon wooden trays that may have been dipped in melted paraffin or coated with water- and acid-proof paint. Sometimes sand is placed, in addition, in the trays. Batteries that are for use in connection with railway circuits or ordinary three-wire lighting systems, in which one line is grounded, must be

provided with especially well insulated supports. After placing the groups of plates in the jars, the positive lug of one is to be joined to the negative of that in the next jar, and so on until finally one extreme positive and one extreme negative is left for connection to the switchboard. In case the equipment includes "end-cells," taps are to be attached, in addition, to some of the intermediate connections. In small installations, lead-covered bolts may be used for clamping the connections, but ordinary brass screws and nuts only in case they are well covered with white lead paint. In large ones, however, the joints are always to be burned together, — an operation requiring the services of an expert.

For preparing the electrolyte, or solution, as few different vessels as possible should be used. The battery jars themselves are not suitable for the purpose; they are too small to insure uniformity in the mixing, and their thickness would introduce considerable danger of cracking from the heat accompanying the mixing. Large earthenware crocks will do, but the acid has a bad effect on the lead glazing, and solution should not be indefinitely stored in such vessels. Pure water must be obtained, and if means of distilling are not convenient, rain water may be specially collected for the purpose, or clean snow melted. Though brook or river water for a city supply may be primarily pure, some iron rust is apt to be found from action on the pipes. Pour the acid in a very small stream into the vessel of water, stopping for half an hour or more, if convenient, to allow for

subsidence of the heat. The solution must be prepared at least a day before using, by which time the temperature should be not much above 60° F., and the specific gravity 1.21, — 25° on the arbitrary Baumé hydrometer scale.

It is understood that a dynamo is available at once after filling the jars, for unless the electrical action is immediately begun an excess of sulphate will be formed, and require long subsequent efforts to remove. Even if the plates have been well formed at a factory, and freshly received, they are shipped in a completely discharged condition, and require considerable overcharge to be re-established. The charging process should be started somewhat cautiously, beginning at about one third the normal rate, say for the cells described in the preceding chapter, at about three amperes, for about four hours, then at full rating for twenty hours, — consecutive if possible, or even longer in the aggregate, until the full brown color of the positive plates is produced, and until the voltage required is 2.6 per cell. The charging rate should then be gradually reduced until one third or one fourth of the normal rate is reached, yet requiring 2.6 volts per cell. Subsequent charges can be stopped when the 2.5 volts per cell point is reached.

Home-made cells requiring initial formation will, of course, take much longer. Indeed, after considerable charging, the discharge may consume but a few minutes; the second charge will be a substantial improvement over the first; the reason seems to be that while the positive plates give the proper color the negatives have not

acquired much capacity. After each of these early charges, the hydrometer test must be made upon each cell and usually the addition of more acid will be needed. Especially if impurities have been present in the materials, some of the acid will have been expended in reactions upon them, some in carbonizing the wooden separators, or in forming an excess of lead sulphate. Some experimenters prefer to use common acid for the initial formation, and then return this with the contained impurities to storage carboys, and make the final setting up with the chemically pure acid. The transfer in case of small cells is very easily made, first rinsing the plates under a faucet, and then setting them into an extra jar containing the pure electrolyte, thereby exposing the active materials to the air for only a few moments.

The discharge should never be carried below the 1.8 volt point, and even then the density should be fully 1.15, but long life for the cells is encouraged if this minimum limit is regularly avoided. If a low condition, however, is unavoidable, or has been accidentally reached, no time should be lost in restoring the charge, or troublesome sulphating will be encountered.

Even if batteries are to stand almost idle, they should be regularly charged, and the level of the electrolyte rigorously watched. Nothing is easier than to neglect things not used, and in keeping with the adage "out of sight, out of mind," additional argument is provided for placing the cells in a conspicuous place, where by daily passing, any untoward happenings may readily be

noticed and remedied. Evaporation of water is often overlooked, and as soon as the edges of the plates become dry, crumbling and sulphating begin. A jar or carboy of pure water should be kept on hand for these replenishings. Batteries for this occasional use or even for some purposes in laboratories can prevent this evaporation and danger of exposure of the plates by having a layer of paraffin oil, such as is used in filling transformer boxes, about one quarter of an inch thick poured on top the electrolyte. The author has had particularly good success with 50 cells in a laboratory equipment treated in this manner. Before using the oil, addition of water was necessary as often as once a week, and sometimes twice a week; but since the oil was used, a filling once in six months suffices. Besides, the spraying of the acid during charge, that formerly made havoc of the wooden trays, is entirely prevented, and though the hydrometer test cannot be conveniently made, the necessity for it has largely disappeared. Of course, in repairing or overhauling the cells, the oil makes a rather nasty mess, but this, too, is not without its compensating features, for the hands unavoidably get smeared first with the oil, and are thenceforth somewhat shielded from the attacks of the acid. When a hydrometer test is to be made, a pipette can be used to draw out a sample of the liquid, first blowing away the oil, before immersing the point of the tube; the sample can be delivered to a test-tube containing the hydrometer. If any oil sticks to the latter, it must be thoroughly wiped off, for its presence would

make the instrument float higher and indicate a specific gravity greater than was the real case.

Open cells catch considerable dust, and sometimes quite undesirable impurities may find their way into the liquid, and some sort of covering may be needed. Plates of glass, even though not covering the whole top, are of some advantage. The objection to placing the cells in cabinets and boxes is that they may then escape due inspection and are not so accessible for repairs.

Though storage cells often suffer more from disuse than use, it is sometimes imperative to remove them entirely from service for six months or more at a time. In such cases, they should first be fully charged, then the liquid siphoned off, and of course saved, and the cells immediately filled with water. Then a discharge should be started, at not greater than the normal rate, the resistance being gradually cut out until finally a complete short circuit exists. Though in the water that has become slightly acidulated the discharge will take but a few hours, the plates should be left in the water from one to two days. This may then be drawn off and the plates allowed to dry.

When the cells are to be restored to duty, the original steps just described must be repeated.

If any cell indicates a low voltage or a low specific gravity, some real cause is to be looked for at once. The trouble will usually be due to short-circuiting between the plates; filling may be bridged across the small gap, or one of the plates warped so as to touch its neigh-

bor. In the case of plates that rest on a ledge in bottom of jar, there may be such an accumulation of mud from the sifting down of the active material as to cause considerable leakage. If the glass cells are placed high in a light place, such a condition may be readily discovered; in this case the remedy is to siphon off the liquid, remove the cell, and wash out the accumulation. Large cells in daily use cannot tolerate interruption of service and must be repaired in place. Such plates are always to be suspended from the top, with such separation from bottom of vessel as to preclude dangers from the mud, but other sorts of leakage paths can be detected by the aid of a small flat incandescent lamp, on the end of a stick. Additional separators often need to be inserted to preserve proper spacing, or old plates may be sawed off, and new ones burned on while the normal current is still flowing.

Of particular difficulty is the case when a large tank springs a leak. To remove the entire cell without either first short-circuiting it, or of opening the main circuit, demands considerable ingenuity and skill on the part of the operator. With the combination of the fiery acid, the gas flame for burning the joints and the flashing of the electric current, the operation is attended with some personal danger. Storage battery manipulation and attendance is becoming an important and highly specialized branch of engineering.

CHAPTER VII

SWITCHBOARD ARRANGEMENTS FOR STORAGE BATTERIES

DEPENDENT upon the opportunities and applications of the batteries the charging arrangement will be subject to considerable variation. Manual operations are usually involved, but in some large installations highly ingenious automatic devices allow the dynamos and batteries to work harmoniously together, and maintain the desired regulation on the system. Simplicity or complication will be had, depending upon the ends to be attained. Three cases only will be here considered. Others would differ mainly in the extent to which automatic rather than manual operations were involved.

In any case the number of the cells is determined by the voltage desired, while the particular size depends upon the number of ampere-hours to be supplied. Often batteries are installed without the full complement of plates, but these are added to keep pace with increased demands.

The simplest case consists of a laboratory or experimental set, without any particular number of cells or intended for any one specified use, and a dynamo is supposed to be at hand, of sufficient capacity to charge

them at full rate. A diagram of suitable connections for charging is given in Fig. 14. Additional circuits are supposed to be attached to the cells in various places, to allow for the varied use of the discharge. The ammeters and voltmeters for battery circuits must assuredly be of the permanent magnet or "Weston" type. Since the battery itself has a definite polarity, the instruments themselves must also have definite poles, or there will be no evidence whether the negative pole of the dynamo is being attached to the positive of the battery, or whether current is going into or out of the battery. As indicated on the diagram, the voltmeter can well have its zero at the extreme left of the scale, the ammeter its zero in the middle. A double-pole single-throw (DP – ST) main switch, a double-pole double-throw (DP – DT) voltmeter switch and a field rheostat are to be conveniently arranged. Fuses are supposed to be inserted in appropriate places. It is convenient to have the positive pole uniformly on the right of all the switchboard apparatus.

If the wiring is as shown as in Fig. 14, the main switch is first supposed to be open, but if the voltmeter switch is turned up, the pressure due to the battery will be measured; this switch is then turned down, and by manipulating the rheostat in the shunt field winding, the potential of the dynamo is adjusted to the same value. If the voltmeter pointer goes the wrong way, that is, to the left, it is proof that the dynamo is of the wrong polarity, and the closing of the main switch under

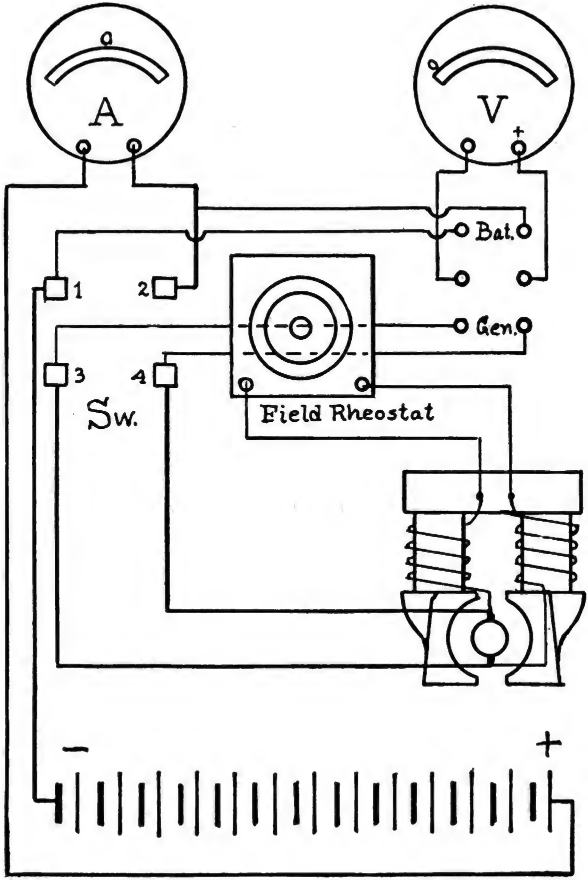


FIG. 14. — Simple Diagram of Connections for Storage Battery Charging.

such conditions would be wrong. After initially connecting the dynamo leads to the proper points of the main switch, no trouble from reversed polarity may be expected, but reversal may occasionally happen, the more especially if the same machine is used for various other experimental purposes. If reversal does occur it is unnecessary to exchange the leads at the switchboard, but proper to restore the poles of the dynamo to their original condition. This may readily be done by first opening the armature circuit. If no switch is on the machine, all the brushes belonging to one set must be lifted off the commutator. Then close the main switch at the operating board. Since the armature circuit has been opened, current will then flow from the batteries through the field only and magnetize it in the desired direction. Now open the main switch, restore the armature circuit, and the polarity will be found correct. Of course, on a pinch, a careful man could depend upon this method of insuring the correct polarity and allow him to use the electromagnetic (magnetic-vane) type of voltmeter, but such procedure is awkward. A shunt-wound dynamo is eminently suited to charging batteries, for in case of ordinary accident the machine would merely be run as a motor in the same direction as it was being driven. A compound-wound field magnet is too likely to acquire a reversed polarity, and a series-wound field is highly out of place. In the latter case it is seen that to allow the machine to generate at all, the circuit must be closed, and as soon as closed, current would flow out of

the battery and reverse the poles of the dynamo. The shunt machine is immune from such dangers, for whether the current comes from the battery or the armature, the direction around the field is the same.

With polarity and voltage correct, the main switch is then closed, but because the two electromotive forces are equal and opposite, — current trying to come out of the battery and flow through the armature, and out of the armature and flow through the battery with equal force, — no current will flow either way. Now, by means of the rheostat, strengthen the current in the field, thereby raising the voltage of the dynamo above that of the battery, and current will be made to flow through the latter against its will, but because work is then being done against a force, energy is thereby stored up. Just how much this elevation of potential should be, depends upon the rated ampere capacity of the battery, and the ammeter in circuit should be so connected as to give deflections to the right for charging, while deflections to the left are indications of discharging. If the voltage required is over 2.5 per cell, some abnormal resistance in circuit should be suspected,— bad contacts between the lugs of the different cells, or a lug partly separated from the plates, being the most frequent causes.

For stopping the charge, reverse steps should be followed, first turning resistance into the field circuit until the ammeter indicates zero, then opening the main switch. This procedure relieves the switch from flashing

and burning, and the dynamo and engine from sudden changes of load.

A second case is frequently met, as when the charging dynamo is regularly devoted to lighting lamps, and the potential therefore fixed; and yet, when dynamo is not running, the battery must supply the same potential. Instances would be small workshops, apartment houses, or pleasure yachts, in which for the greater part of the lighting the dynamo would be kept running, but for the rest of the night a few lamps only would be needed, and these to be supplied from the battery.

The number of cells would be determined by the voltage desired divided by the minimum allowable voltage per cell; taking, as a practical example, the case of a 110-volt plant, and 1.8 volts per cell as the limit. $110 \div 1.8 = 61$. The losses in the line wiring would probably be negligible for the small loads admitted, but an even number of cells is desirable, so 62 would be the required number. These should then be placed in two groups, each consisting of 31 cells in series. A rheostat of sufficient size to carry double the discharge rate of current is also to be provided, and the whole connections be theoretically made as shown in Fig. 15. As readily seen, this cut represents the two groups charging in parallel through the rheostat, and discharging in series through the same rheostat.

It will be recognized that by reason of the interposition of the resistance on both charge and discharge, this method of operation is doubly wasteful of energy.

Further, the system is inconvenient, as adjustment of the rheostat is necessary for every change of load. This latter is not serious, however, as the load is supposed to be nearly constant, and the correction can periodically be made by the watchman.

An actual arrangement of the apparatus for controlling the charge and discharge is given in Fig. 16. S_1 is the

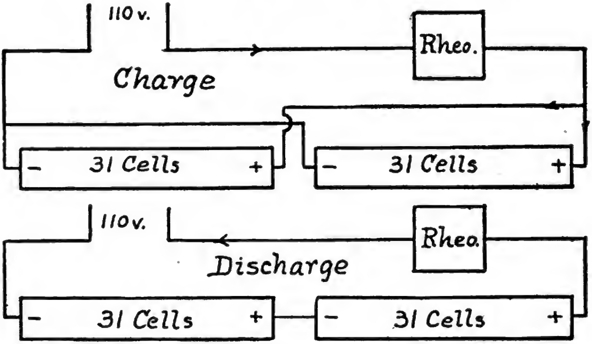


FIG. 15. — Diagram of Connections for Constant Potential Charge and Discharge.

main switch, the positive pole of the supply being at contact 2. S_2 is a double-pole double-throw switch of the same ampere capacity, having the hinges at 5 and 6, therefore swinging in a horizontal manner. When turned to the right, the two groups of cells are connected in parallel, and the entire charging current passes also through the underload circuit-breaker, the rheostat, over-

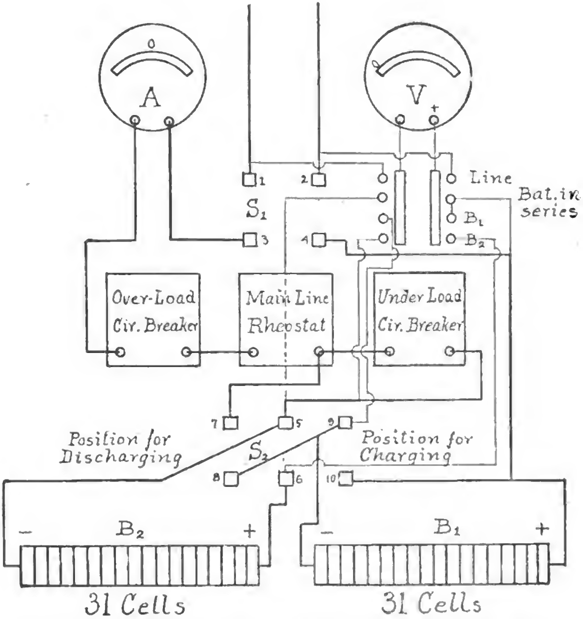


FIG. 16. — Actual Switchboard Arrangements to Comply with Preceding Diagram.

load circuit-breaker, and ammeter. The latter has its zero in the center of scale as in the former case. In all regular storage battery installations, underload circuit-breakers are imperative, otherwise, by inattention at the

dynamo, the cells may ruinously run down. Such a switch is held closed by the normal charging current, but when below a predetermined minimum it automatically opens. The overload circuit-breaker is merely a convenient substitute for a fuse.

A four-point voltmeter switch is shown, with such an arrangement of sliding contacts that, at will, the voltage across the line, that of the two sets of cells in series, or of either set singly, may be read. When switch S_2 is set for allowing the discharge the underload circuit-breaker is short-circuited. Unless some current is actually flowing, the voltage across the line will, of course, be the same as that of the 62 cells, for then the rheostat would be inoperative. From reference to Fig. 15 it will be observed that during discharge the current necessarily flows through the line in the direction opposite to that during the charge. If a motor was connected, there would then be a moment during the transfer when it would be without field magnetism; its automatic rheostat would then open the armature circuit also, therefore a motor would require starting anew.

With such a series-parallel-rheostat control, the minimum voltage lost in the rheostat during charge, *i.e.*, at the end of a full charge, would be $110 - 31 \times 2.5 = 33.5$, and during the ordinary part of the discharge the loss would be $62 \times 2 - 110 = 14$.

A switchboard arrangement that allows economical and flexible control, whether on a large or a small scale, is shown theoretically in Fig. 17, and diagrammatically,

yet with actual order, in Fig. 18. It represents an ordinary two-wire system, but it could readily be doubled for adaptation to a three-wire system. By its provisions four desirable conditions are allowable: *i.e.*, (1) Operation of the lamps directly from the dynamo, the battery being cut out of action; (2) conversely, operation by the battery alone, the dynamo being shut down; (3) simultaneous supply of current from the dynamos to light the lamps and charge the battery; and (4) dynamo working in parallel with the discharging battery to supply the

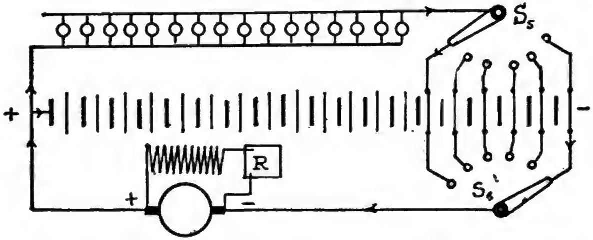


FIG. 17. — Diagram of Connections for End-Cell Control of Charge and Discharge.

lamps. While the battery is supposedly either charging or discharging, it will be recognized that to admit renewals or repairs, the first condition should be provided for; the second condition would regularly fit a small plant for the late hours of the night, but in a large central station these hours would industrously be spent doing most of the charging called for under the third head; under the fourth head, the "peak" of the load, between

five and seven o'clock in the winter evenings would be carried.

From Fig. 17 the arrangement is seen to consist essentially of a shunt-wound generator, having one of its brushes attached both to the battery and the loads; the other brush is attached to the pivot of an "end-cell" switch, and the other line wire is attached to a similar but separate switch. If in this case the positive pole of battery is imagined on the left, current from the generator can flow through the battery in the direction to charge all the cells, returning by the contact on the last cell, also will supply the lamps, but that part of the current will be obliged to flow through the end cells in addition to the other charging current. In operation, therefore, these cells will be more quickly charged than the rest, and should speedily be removed from circuit by proper manipulation of the end-cell switch, and the dynamo potential be suitably reduced. For working in parallel, both end-cell switch arms rest on similarly numbered contacts. It will be noticed that the spaces between these contacts are relatively large. This is important; otherwise, if the arm should bridge across two contacts a cell would momentarily be on a short circuit, with ruinous consequences to itself and to the switch. If the installation is large enough to require alleviation of the flash at the exchange of contacts, or to avoid the wink in the lamps, the contact arms may be made double, and the two parts insulated from each other except as connected through a resistance strip. Thereby, in the

passage from one contact to the next, the resistance is momentarily interposed between the battery terminals. Regularly this extra arm stands midway between two contacts, and is therefore out of circuit.

In Fig. 18 the directions of the currents are made to conform with Fig. 17, *i.e.*, giving condition (3). The number of cells in the main battery, however, is abbreviated to make clearer the connections of the end cells. For convenience only 12 such are shown, but the actual number would of course be determined by the voltage decided upon for the system. For 110 volts the total number would consist, as before, of 62 cells. For charging all of these the dynamo would need to have a capacity of $62 \times 2.5 = 155$ volts. If preferred, an ordinary dynamo with a working range of 110 to 125 volts may be used, and then a suitable "booster" or dynamo for supplying the rest of the volts connected in series. The regulation would be accomplished by varying the field excitation of this booster, or by cutting the machine altogether out of circuit. Taps should be taken off from such a number of end cells as will allow the lamps to get only 110 volts, though the dynamo may be supplying 155. With the inferred allowance of 2.5 volts per cell, this number will be the difference between 155 and 110 divided by 2.5, or 18. Probably 16 would be found sufficient to give all the variation needed. In Fig. 18 some of the end-cell taps are omitted for sake of not obscuring the rest of the lines, but the reader can easily imagine their existence.

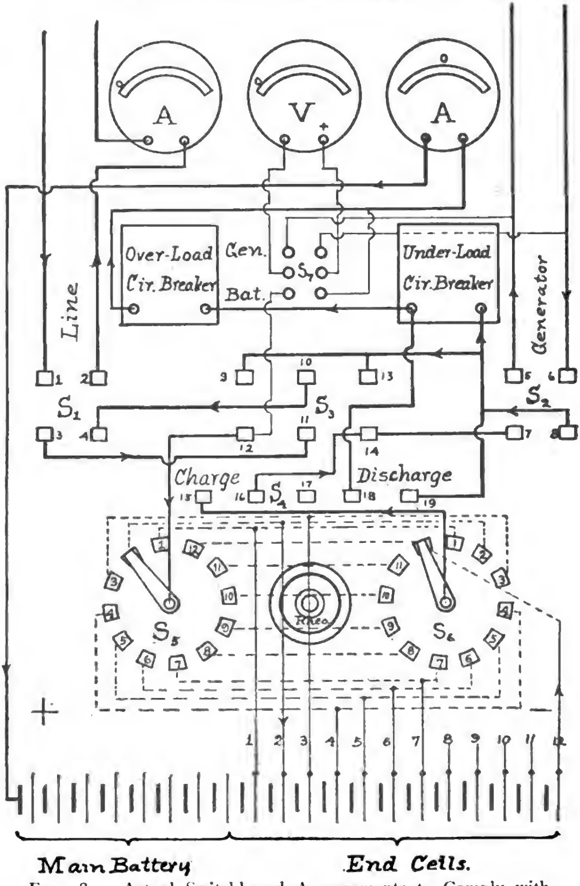


FIG. 18. — Actual Switchboard Arrangements to Comply with Preceding Diagram.

In the diagram, S_1 is the line switch, for connecting or breaking the lamp circuit; the hinges are at points 3 and 4. S_2 a similar switch hinging on points 7 and 8, and is in the generator circuit. Switch S_3 hinges on points 10 and 11, and can connect with 9 and 12 or with 13 and 14. S_4 is a single-pole double-break switch hinging on 17 and capable of connecting with 15 and 16 or with 18 and 19. S_5 and S_6 are the two end-cell switches. Between these the field rheostat hand wheel may conveniently be located, but the resistances themselves may preferably be at the back of the board. S_1 is to be taken as representing one of several circuit switches, for if alone its functions could be performed by S_3. That condition (3) is complied with may be proved by imagining S_1 and S_2 closed, with S_3 and S_4 turned to the left. One path from generator is by contacts 6 and 8, through the two circuit-breakers and ammeter to battery; then leaving battery by contact No. 12 of S_6, current passes through contacts 15, 16, 14, 7, and 5. At the same time current also passes directly to line from generator by the path 6, 8, 9, 10, 4, and 2, then returns by 1, 3, 11, 12, end-cell switches S_5 and S_6 to 15, 16, 14, 7, and 5. To cut out the battery, and supply the line alone from the generator, S_3 is turned to the right and S_4 left open.

For discharging the battery, S_4 is turned to the right and S_3 to the left, the former thereby short-circuiting the underload circuit-breaker. The path of the current is then from positive pole of battery through ammeter,

this now showing a reversed deflection, — overload circuit-breaker, to 18, 19, 9, 10, 4, and 2, to line, returning by 1, 3, 11, 12, to S_5 and negative pole of battery. With S_1 open, the battery alone supplies the line, but with S_2 closed, and the end-cell switches resting on similarly numbered contacts, generator and battery work in parallel. From whichever source the line at any time receives its energy, the current always flows in the same direction, — a condition of importance for the correct registering of meters. The ammeter in this circuit should then have its zero at the left of scale as shown. If the ammeters have external shunts, their location can be a matter of convenience, that for the battery circuit being readily placed between the two circuit-breakers. For the voltmeter, only two connections are needed, — one for generator and one for battery.

One other arrangement for a storage battery is known as that in which the regulation is effected by use of "counter cells." These may consist merely of unpasted grids, but immersed in acid of the ordinary strength. The entire main battery is connected to the generator, and all these cells charge alike. The discharge, too, is uniform but takes place through a variable number of counter cells, as controlled by a switch similar to that for end cells. It is seen that the counter cells take current always in the direction to charge them. Of course such a system is not the most economical of power, but is often prescribed for such places as receive meager and even indifferent attention.

It is possible that for rural or other small private lighting installations, especially in connection with low voltage tungsten lamps, regulation by use of counter-cells will acquire considerable popularity. The apparatus may be described as somewhat more "fool-proof" than those that possess a higher operating economy.

The front view of a complete switchboard for the counter-cell control is given in Fig. 19. As viewed from the rear, the connections would appear as shown in Fig. 20. A single voltmeter is used, but fitted with a 3-point switch, so that (1) the potential of the generator can be read, (2) that of the main battery, and (3) that of the lamp circuit, — that is, of the main battery as modified by the counter-cells. Two ammeters are shown. One has a single scale, for indicating the entire current from the generator. It is represented as having an external shunt, located near the double-pole double-throw switch at the bottom of the panel. From it small wires lead to the instrument itself. (The aid of a magnifying glass will bring out these and many of the other connections that are necessarily drawn on a small scale.) The second ammeter has its zero mark in the center, and is for indicating the current flowing into or out of the battery. It is represented as being of the self-contained type, that is, with an internal shunt, therefore full sized wires lead to it. The 18 points of the counter-cell switch are connected with the cells in the order

numbered, but to have shown these wires would have confused the diagram.

An underload circuit breaker is shown, but this is available only when the generator switch is turned to the special "charge" position. When lamps are to be supplied directly from the generator, the voltmeter is connected to position 1, and by means of the field rheostat the potential adjusted to the desired value, say 110 volts. The main switch that was standing outright from the face of the board is then closed to the left position, marked "lights." Such of the four circuit switches as are desired are then closed. If it is desired to charge the batteries alone, the counter-cell switch is turned to position 1, the voltmeter switch to position 2, the pressure is observed, then, after moving to position 1, the generator pressure is adjusted to that same value. The main switch is then turned from its open to the "charge" position, on the right. The underload circuit breaker is then closed and held by hand until, by suitably raising the voltage of the generator, there is enough charging current passing to hold it in that position.

A 110-volt equipment will require about 62 cells in the main set; therefore for charging them at a final pressure of 2.5 to 2.6 volts per cell, the generator will be called on for as high as 155 to 160 volts. An ordinary 110-volt generator may not be able to supply this without undue heating of its field magnet coils, so special care should be taken, when making a purchase, to ensure this rating. If lights are to be operated during

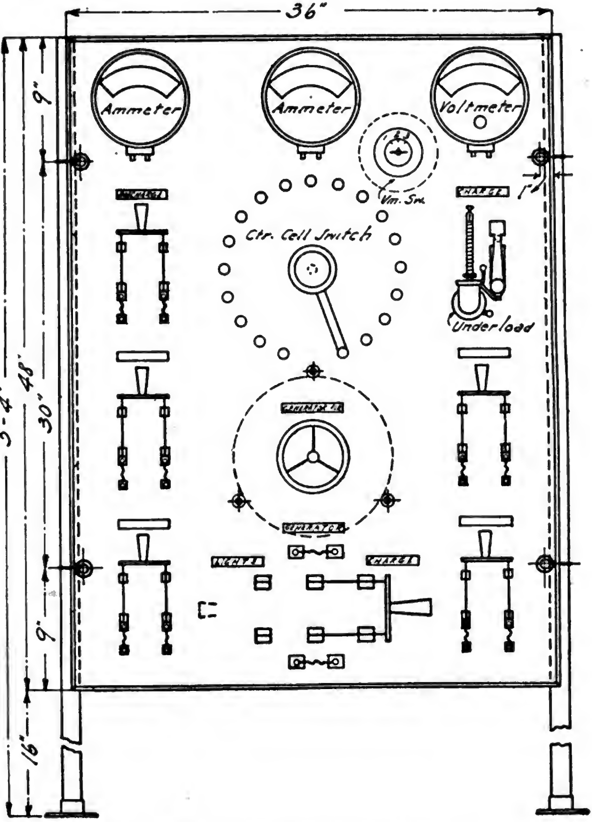


FIG. 19. — Front View of Switchboard adapted for Counter-Cell Control.

the charge, the "discharge" switch directly under the battery ammeter is to be closed, the voltmeter switch turned to position 3, and the counter-cell switch then turned until the pressure is sufficiently reduced for the lamps. Eighteen counter-cells will, however, take off only 36 volts, so that no attempt should be made to operate the lamps when the batteries are receiving the final portion of their charge. It will not ordinarily be found necessary to put in a larger number of these counter-cells.

For carrying "peak" loads, the generator and battery may be made to work in parallel. To accomplish this, the field rheostat is turned to such a position that the battery ammeter stands at zero, and such adjustments are then made with the counter-cell switch and rheostat that the voltmeter reads the same for all three of its switch positions, and the currents as shown by the two ammeters should not be allowed to exceed the rated capacity of the apparatus.

For the case of low voltage lamps, as suggested on a former page, say for 27 volts, which seem likely to become standard, the number of cells required would be directly proportional, being about 16 in the main set and 4 in the counter. Not so close regulation would be possible, for the act of moving the cell switch one point would alter the pressure by the full 2 volts, which is a much larger percentage of 27 than it is of 110. Happily, tungsten lamps are not so sensitive to alterations of voltage as are those with carbon filaments. The generator should be able to supply 40 volts.

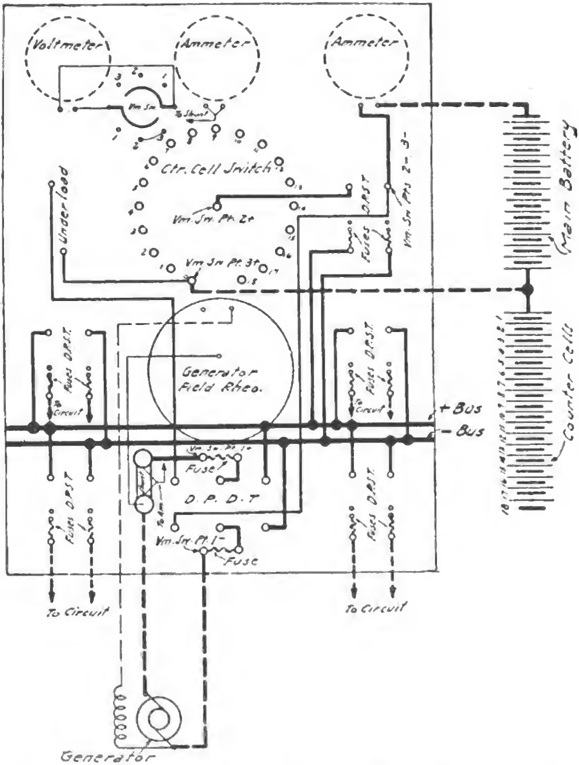


FIG. 20. — Diagram of Connections of Board Shown in Fig. 19, as Seen from the Rear.

CHAPTER VIII

BOOSTERS

Convenience in charging and discharging batteries, or securing almost automatic control, can be secured by the use of boosters. Such machines are merely special dynamos, of smaller size than the main generators, and though often of large current capacity exert a relatively small electromotive force; they are usually driven by direct-connected electric motors, but could, under favorable conditions, be as well actuated by steam engines or water wheels. In consequence of the large currents to be carried the commutators often appear overgrown, but the field magnets resemble those of ordinary machines.

Considerable finesse has been attained in the development of applications of boosters, the variations being largely found in the method of exciting the field magnets. Though denoted by the familiar terms of shunt, series, compound, differential, and constant current, these names have a specialized meaning, and in actual use might not be readily recognized by other than an expert engineer. The exact diagrams of connections for the several cases would involve a detour and extended ex-

planations outside the scope of this book. A definition of each sort with a reference to its particular application will suffice.

Shunt booster. A numerical example will illustrate the case. A dynamo is to operate 110-volt lamps and also charge a battery, so that, later, the two may supply the demands in parallel, or the battery alone carry the final part of the load. Unless the devices shown in Figs. 17 and 18 be used, the dynamo can run at 110 volts only, yet the number of batteries, as earlier explained, must be about 62, and at 2.5 volts per cell require 155 volts. This difference can be supplied by a special dynamo, with its armature in series with the main generator; the maximum additional voltage needed is $155 - 110 = 45$, and since the total voltage has been raised, the special dynamo is graphically designated as a "booster." The field is excited by a shunt circuit tapped from the main bus bars, rather than by a branch of current from its own armature. By means of a rheostat in this field circuit, greater or less excitation can be provided, and such a voltage added to that of the main generators as required to give the normal or desired rate of charge. When this field circuit is broken, the armature will merely be inert, and can then properly be short-circuited. For overcoming the ohmic resistance of the cells and assisting them in the discharge when carrying the "peak of the load," the field circuit is reversed, and the booster potential added to that of the battery. If this reversible feature is regularly available, it is possible

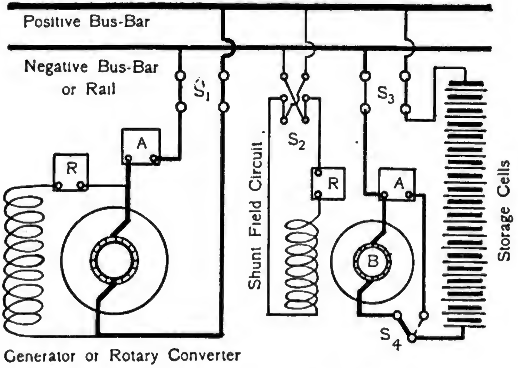


FIG. 21.—Diagram of Connections for "Shunt" Booster.

In this and the three following diagrams, an ammeter is designated by A. a rheostat by R, booster by B, and various switches by S with subscript numbers. Their functions are so obvious as to require no detailed explanation.

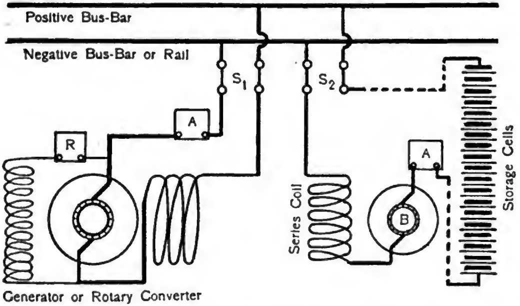


FIG. 22.—Diagram of Connections for "Series" Booster.

The use of the dotted lines in this diagram is to signify that the battery is at the end of a long feeder, while the booster itself is in the main power house.

to dispense with the use of end cells, and their cost together with that of the leads and switches may be equal to that of the booster. There would be the necessity, however, of always running the booster, when otherwise the machinery might be shut down. A further disadvantage consists in the fact that since the discharge rate of storage batteries in central stations is ordinarily much higher than that of charge, the booster would needs be large enough to pass the maximum current.

Series booster. In an earlier chapter it was explained that an ordinary series dynamo was impracticable for charging batteries. The series booster is an apparent exception, but still it serves an auxiliary purpose only, in connection with the regular shunt generator. The battery and booster are connected in series across the main line, resembling the simple case of a "floating" battery. If no current is flowing either into or out of battery, the field magnet is not energized, and no electromotive force is exerted by the revolving armature. If now, in consequence of a reduction of load on the line, the generator potential rises, a charging current will flow into the battery, and magnetism be produced in the field of the booster to increase that current. When sudden demands on the line lower the pressure to a point less than that of the battery, current will flow out, reverse the polarity of the booster, and this latter will then assist the battery in supplying the demand.

In removing such a machine from circuit, its field magnet must first be short-circuited, then the armature.

By no means should the armature be the first to be thus treated, for it or its driving motor would be in danger of burning out, nor should the motor switch be first opened; for in this case the booster would at once become a simple series motor without load and might so speed up as to fly to pieces. The regulation sought by series boosters is better attained by the means next to be described, therefore is not now used.

Compound booster. In this the armature, series coil, and battery are connected across the line, — in this respect being identical with the preceding case. In addition, a shunt coil, with rheostat and reversing switch, is connected across the line, the joint action being, as suggested by the name, a combination of the two simple methods. Its application is found in railway or other power circuits in which the fluctuations of load are sudden and severe. In order to make a practical installation, exact data are needed as to the instantaneous loads, and the current capacity of the booster as well as the degree of saturation of the field magnets carefully computed. The aim is to keep the load on the generators fairly constant, thus ensuring economical operation, and to let the fluctuations be borne directly by the battery. The generator is supposed to be suitable for carrying the normal load, and the shunt field current in booster is always flowing in the direction to generate an electromotive tending to discharge battery. No actual discharge, however, may take place, for the number of cells and voltage of booster are so adjusted that the sum

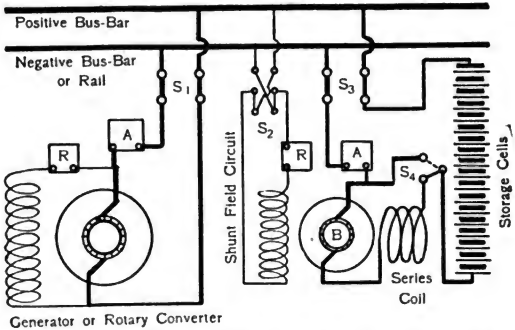


FIG. 23.—Diagram of Connections for "Compound" Booster.

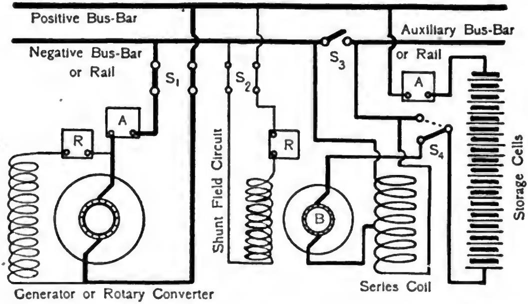


FIG. 24.—Diagram of Connections for "Differential" Booster.

of their voltages is only just equal to that across the line. If now, by an increase of load, the voltage of generator falls, current will flow out of the battery, and in so doing will pass around the series coil in the direction to increase the magnetism, and generate an electromotive force to accelerate the discharge. The battery, therefore, at once assists the generator, even to the extent of assuming the greater share of the load. Conversely, by a suitably diminished load on the line, and rise of potential at the generator, current will begin flowing into the battery, but now in reversed direction through series coil, whereby the effect of the shunt is diminished, or even reversed, and thereby still further encouraging the charge. In actual operation, the variations of potential required to effect these ever changing conditions are surprisingly small.

Differential booster. In this, as in the preceding case, the end sought is to maintain constancy of load on generator and of voltage on line, in the face of wide and sudden variations in demand for current. In a highly satisfactory degree these results are actually realized. All the current from the generator, or in the particular feeder circuit to be regulated, passes through the series coil of the booster, and in the direction to produce discharge; the current through the shunt coil, tapped across the line, flows in the opposite direction. At normal generator load, these two magnetomotive forces are equal, no booster electromotive force is generated, and the battery is idle. If now an increased demand for

current is made, there will at once be, without the necessity of a fall in potential, an increased magnetization due to the series coil; the shunt will be overpowered, and the battery will begin to discharge. With less than normal current in the line, the series coil will be less energized than the shunt, and the booster will then generate an electromotive force in the direction to charge the battery.

A more specialized case of the differential booster is that in which the series coils are wound in two parts, as shown in Fig. 24. One of the busbars is represented as being opened by the switch S_3, and to these two points the terminals of the entire series winding are connected. At the middle or some proper point of this winding the armature of booster is connected; other armature connection is led to negative pole of battery, positive being connected to line. With normal load, the battery is inert. This condition is brought about by so adjusting the shunt field rheostat that the ampere-turns due to both series and shunt windings will just cancel each other, the series coil being connected in the direction to discharge the battery, the shunt to charge it. Since the function of the booster and battery is to maintain a constant load on the generator, independent of exterior demands, the current through the upper part of the series coil may be considered as constant, while that in the other portion is the sum of the generator and battery currents, and may be subject to extreme variations. If

the demand exceeds the desired limit of the generator, the effect of the series portion of the field winding predominates, and an electromotive force is generated in the booster in the direction to help the battery to discharge, thus supplying the particular demand. When, by reduction of the load, less current flows into the line than is the capacity of the generator, the effect of the series winding is diminished to a point below that of the opposing shunt, the polarity of the booster is reversed, and the battery at once begins to charge.

A differential booster of this sort, for relatively large output, is shown in Fig. 25. It has eight field poles, is capable of carrying 160 kilowatts at from 55 to 110 volts. The motor which drives it, at a speed of 450 revolutions per minute, is of 230 horse-power, and is supplied with current from the main busbars at a pressure of 550 volts. The number of the flexible cables and the size of their terminals is suggestive of the large currents, about 1500 amperes, that are to be carried with only small losses.

Constant current booster. In some cases it is desirable to avoid the attempt to maintain constancy of voltage, but to limit the supply of current, letting the voltage fall to fit the needs of the apparatus. Such circuits would be for power, of course, rather than for lighting, and especially for that sort of power as demanded frequent stops and starts. Since rheostats are necessarily employed in starting these devices, being

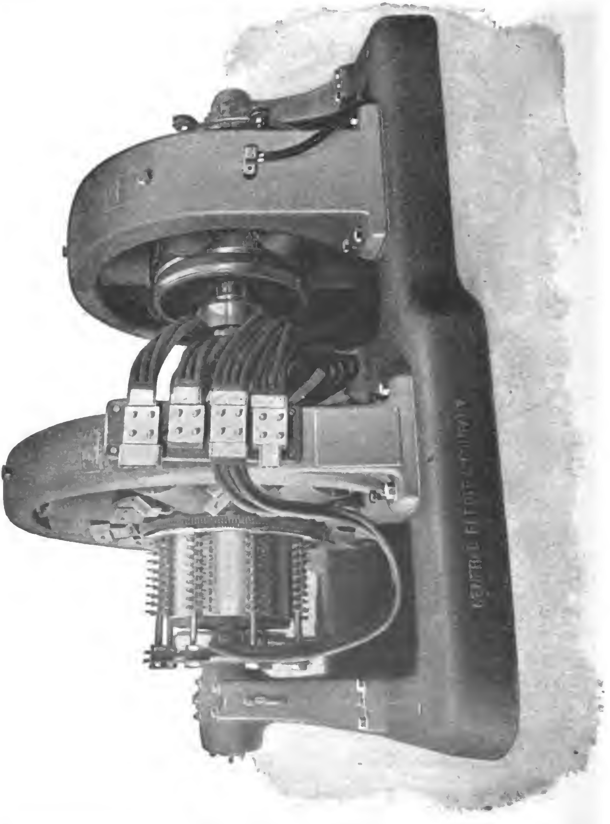


FIG. 25. — 1500-ampere Differentially-wound Booster, made by the General Electric Company.

used to cut down the voltage impressed upon the motors, some propriety would be seen in automatically cutting down the line potential at such instants and diminishing the rush of current. The generator is supposed to be of the constant potential type, and may well supply lighting circuits in addition to its motor load. In the power circuit is inserted the armature and series coil of booster, and this circuit, therefore, never experiences reversal. A shunt coil is tapped across the line, and produces magnetism in booster in the direction to assist generator to charge the battery; the series coil opposes the shunt. Battery is connected across the power circuit, as if floating on it. When an extra demand comes on the power circuit, increased current flows through the series coil, resulting in a diminished booster voltage, whereby the charging stops, relieving the generator to that extent, or in case of still greater demands, the batteries discharge and directly assist the generator.

"Carbon" regulator. This device, made by the Electric Storage Battery Company, consists of two piles of carbon disks, *k*, *l*, Fig. 26, above which is pivoted a lever *AB* actuated by a solenoid *C* connected in series with the main line. The pull of the solenoid *C* is balanced by an adjustable spring. The conductivity of the piles of disks depends upon the force with which they are pressed together, which, in turn, depends upon the main-line current through the solenoid. Booster field is excited by a small dynamo, the field

of which is connected between the middle point *b* of the battery and a point *c* between the piles of disks. During heavy load, disks *k* are compressed and disks *l* are allowed to separate; current then flows through the path *b-d-a-c-k-f*. During light load, the spring pulls the other end of lever down, disks *l* are com-

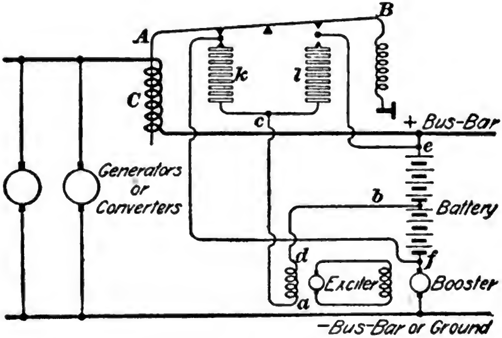


FIG. 26. — Carbon-pile Regulator for Booster.

pressed, and disks *k* allowed to separate; current then flows through the path *e-l-c-a-d-b*, that is, in the reverse direction through the exciter field. The exciter field is thus automatically excited in either direction, according to the line load, and the booster is made to assist or to oppose the battery.

In one important respect, regulation by use of automatic boosters fails to meet all the conditions

imposed. Their function has ordinarily been to maintain a certain average load on the generators, and to transfer the fluctuations to the battery. Yet a booster could not distinguish between a rapidly fluctuating and a slowly changing load; that is to say, if the regulating system were set for such a certain load, it would tend to hold the generators at that load regardless of the duration of the change in the outside demand; and the only method of altering the output of the generators would be by hand alteration of the rheostats or adjusting springs. Cases have been found in which the battery has had to take not only the fluctuations for which it was designed, but also had to handle "peak" loads of long duration which were not noticed by the station operatives. To avoid the danger that the battery might unexpectedly be quite run out, an automatic average "adjuster" has been devised, which will properly change the apportionment to the generators with sustained changes in outside loads. This device consists of a small motor actuating the booster regulator through a reducing gear. The principle is that on a discharge of the battery the motor revolves in the direction slowly to raise the load on the generators. On a charge of the battery the motor runs in the opposite direction, thus slowly relieving the generators of load.

It is evident that a battery equipped with such a device will still take the rapid fluctuations, but will not hold the generators to a fixed average, the sustained changes being more properly transferred to the machines.

CHAPTER IX

THE CADMIUM TEST FOR THE CONDITION OF BATTERY PLATES

To maintain the voltage is not the only aim in use of batteries, but to maintain the capacity, *i.e.*, the ampere-hour rating. It is evident that if one plate is fully formed, while the other is only partly so, the charge will quickly run out. Especially in the making of new cells is the capacity apt to be small; the plates may have the right color, but the builder usually imagines that the positives are incompletely formed. This is likely to be true, but it is quite as possible that the negatives are still less reduced to their proper spongy character. A voltmeter will indicate the difference of potential between the two plates, but it offers no reliable information as to the condition or extent of the charge. For this, each plate must be tested independently. A pencil of cadmium used as one electrode, in comparison with the two regular plates, to give deflections on a suitable sensitive voltmeter, allows for a considerably reliable determination. The latter instrument must be of permanent magnet type, and capable of reading within .01 volt; one of the "Weston" laboratory pattern, with the

low scale calibrated for 3 or 5 volts, will be eminently suitable.

It is important not to allow the cadmium to come into actual contact with either plate, and to forestall such a contingency the pencil may be permanently slipped into a perforated rubber tube. It is better also to leave the metal with its natural slightly oxidized surface than to introduce variations due to more or less effectual cleaning.

In the electrochemical sense, cadmium is much like zinc, — indeed, chemically pure zinc can be used in place of cadmium in this test, — and is electropositive towards ordinary lead. That is, if a galvanic couple be made of these two metals, cadmium would be dissolved, and a current of electricity would start from it, pass through the electrolyte to the lead plate, thence to the outer circuit. This phraseology is at once suggestive to the reader of some confusion that exists in the name of the plates, but a little care will always enable him to locate the true significance. That pole from which the current is led to the external circuit is certainly the positive one, but it is as equally certain that the current actually had its origin at the other plate, and it is to this latter that the current finally returns. To avoid complications of speech, it is common and sufficient to call the positive pole the positive plate, but in the ultimate analysis the opposite terms are seen to be justified. It is recognized, — conspicuously as in the case of the storage battery, — that considerable difference of electrical potential may

exist between a given metal and its various oxides or other compounds. A certain difference of potential exists between cadmium and lead in the spongy form, and a somewhat different amount between cadmium and lead sulphate; mixtures of metallic lead and different quantities of the sulphate would be expected to exhibit

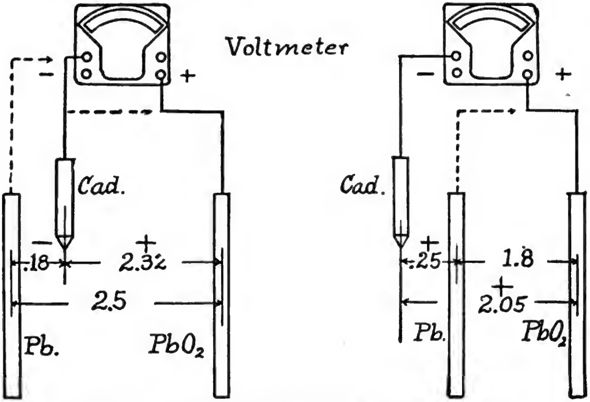


FIG. 27. — Voltmeter Connections for Cadmium Test.

intermediate differences of potential. Between cadmium and peroxide of lead, or peroxide mixed with sulphate, a still further difference of electric potential is found.

By reference to Fig. 27 it will be seen how these readings are made, and what is their significance as to the degree of charge or discharge of a battery. Current is

supposed to be flowing, and it is desired to know if the cell is sufficiently charged, or has been discharged to a safe limit. If the charging condition is first met, attach the cadmium test piece to the negative side of the voltmeter, using, of course, the low scale; touch the wire that connects with the positive or push-button side to the black, or PbO_2, plate of battery. The reading may be 2.32 to 2.35 volts. Now touch this positive wire to the other, or Pb, plate; the needle of voltmeter will be deflected the wrong way; therefore the two wires must be exchanged, putting that from the cadmium to the right-hand side of instrument and the Pb wire to the left, as indicated by the dotted lines; a reading of .18 to .20 volt may then be observed. Since the one reading was positive and the other negative, the real difference of potential between the Pb and PbO_2 plates will be the *sum* of these two numbers, or 2.5 to 2.55 volts; and when these figures are attained, both plates are fully formed and the battery is charged to its full capacity. If considerably discharged, the cadmium test piece is to be attached, as before, to the left-hand side of instrument, and the other wire touched on the PbO_2 plate; a reading of 2.05 volts may be obtained; now touch this same wire to the Pb plate, as shown by the dotted line, and a reading of .25 volt may be obtained, and this, too, without exchanging places with the cadmium wire. The cadmium is then electropositive to both plates, and the difference of potential between the Pb and PbO_2 is then found by *subtracting* one number from the other, giving

as a result 1.8; when this condition is reached the cell should not be further discharged.

The geometrical location of the parts in Fig. 27 is intended to be suggestive of the actual change of potential difference. With battery in the fully charged condition, the cadmium is electropositive to PbO_2, but electronegative to Pb; therefore the voltmeter wires needed exchanging; when discharged, the cadmium is electropositive to both, though more so to one plate than to the other, and the wires did not require changing. In passing from the fully charged to the fully discharged state of battery, the negative plate moved up to the position occupied by the cadmium, and then passed by to a distance even further on the other side. From such a graphic diagram one can gain the idea that the negative plate is by no means an inert one, but is vitally concerned in the operation of the cell.

CHAPTER X

DISEASES OF STORAGE BATTERIES AND THEIR REMEDIES

MENTION has necessarily been made in earlier chapters regarding certain defects or causes of deterioration of battery plates. Some of these are so insidious and detrimental as to be worthy of a more detailed description.

Of the apparently mechanical order are the buckling, warping, or other distortions of plates, flaking off or falling out of the active material, and hardening or crumbling of plates due to exposure to air. It is rather remarkable how fully these causes, together with kindred ones such as loss of capacity, reversal of negative plates, and internal discharge, can be attributed to "over-sulphation," or what is more commonly called merely "sulphating."

As seen from the equations that denote the probable chemical actions during the charge, the lead is first changed into the sulphate and then into the spongy metallic or highly oxidized condition; that is, the sulphate is a natural stage between the two extreme conditions found on negative and positive plates. In the normal action of the cell, sulphate is formed no faster

than it can be reduced to either of these two forms by the action of the current. Also, during the discharge, both plates tend to return to the condition of the sulphate. If an excess of sulphate is formed, a cell may be expected to manifest it in some or all of the manners just mentioned.

The sulphate in itself is almost a non-conducting body, and when on a plate it effectually removes the covered portion from further action. Acid that is too strong or too weak is conducive to this formation, likewise long periods between use and successive charging. Of course, the sulphate forms unevenly on the outer surfaces of plates, therefore leaving some parts more active than others, and though the grids may be of symmetrical shape and of equal mechanical strength in different parts, serious warping may result. Films of sulphate may form between the active material and the walls of the grids, thereby leaving the pellets quite insulated from the main circuit. The charging would then be confined to a smaller than the expected quantity of material, and the capacity of the cell be proportionately reduced. With its proper hold on the grids relaxed, the pellets will flake or fall out, resulting in a permanent loss of actual volume of plate. With only a small resulting capacity, such cells are more quickly discharged than those in proper condition, and if the normal discharge is maintained, current from the other cells will continue to flow through the exhausted ones, and reverse their polarity.

The sulphate is readily detected by its white color, and is usually to be looked for on the negative plates only. The outer and visible surfaces of these plates may exhibit some sulphate, even when the other parts are healthy, for these surfaces are so remote from positives as to be largely inert.

Three practical methods may be followed for removal of the undesirable sulphate, depending upon the size of cells and means at hand, as well as upon the severity of the case; the user would select the one most available of the three.

One method is to charge the cells at a slow rate for a long time. Where no immediate urgency for the use of the cells exists, this is perhaps the most practicable plan. If the main cells are in daily use, the defective ones may receive an equivalent treatment by connecting them in on the charge, but switching or cutting them out of circuit during the discharge. Large cells, in which the positives of one are permanently joined to the negative of next, could obviously not utilize this method. A whole double set of plates would require removal and the substitution of a spare set while the faulty ones were being treated in some special vessel. A more common method is to saw off the faulty plates, one by one, replacing them as fast as removed by new or freshened ones.

A second method, highly practical and effective, is temporarily to reverse the negative plates. This process should be carried out, not with the regular positives, or they would be seriously injured, but with "dummies,"

mere slabs of sheet lead used as positives. By this reversed action of the current, the sulphate will be thoroughly converted to peroxide, and then when returned to regular formation there will be the normal quantity of spongy lead free from excess of sulphate. Except for such actual loss of material as may have resulted from flaking, this process restores a plate to almost its original vigor.

A third method may be followed when it is imperative to repair a cell in the shortest possible time, or when the plates have long been dry and exposed to the air. Carbonate of soda is added to the electrolyte, and the normal charging rate maintained until the plates resume their normal color. When restored in this manner, the contaminated solution must be withdrawn, the plates thoroughly washed and set up with fresh solution.

Aside from the internal discharge between plates due to the bridging of pellets of active material, dislodged by sulphating or other causes, discharge may result from the presence of impurities contained in the original materials or absorbed from the air. Particularly pernicious is the presence of even small traces of nitric acid that may have been used in the forming processes. If cells are located in a stable or near refrigerating apparatus, from which ammonia fumes may be absorbed, nitric acid will at once be produced, and the cells possibly ruined. If such locations are unavoidable, the use of a layer of paraffin oil on the electrolyte is an effective safeguard.

From some unexplained reason, direct sunlight seems to encourage the warping of plates. Therefore, while it is highly desirable to locate batteries in places where plenty of light may be had to allow for thorough inspection, an excess should be avoided. Direct sunlight, too, would produce unnecessary evaporation of the electrolyte. Heat is conducive to chemical action. At ordinary temperatures a substance may be quite unacted upon in a given solution, but let the liquid be heated, say to boiling, and dissolution or other action may quickly follow. So with the storage cell. At ordinary temperatures the unwanted actions may be entirely absent, but in a room heated to over 100° F. these chemical changes may be permitted. It is certain that temperatures uncomfortable to person are also unfavorable to battery maintenance.

CHAPTER XI

EFFICIENCY OF STORAGE BATTERIES

THOUGH high, the efficiency is by no means close to 100 per cent. The figures usually supplied by manufacturers are based on ampere-hour operation rather than on watt-hours, the reason probably being the more favorable showing. Some losses are unavoidable, and a few of the more important will be mentioned.

In considering the total economy resulting from the use of a storage battery, the interest on the investment should be taken into account. The size and weight of the cells, and the expenditure of energy in formation, make them expensive, and this weight is very much more than the exact quantity of materials called for in the chemical reactions would indicate; 3.87 grams is the chemical equivalent of lead in ampere-hours; that is, in one hour a current of 1 ampere will precipitate 3.87 grams of metallic lead out of a lead compound, or by reversed direction will convert 3.87 grams of metallic lead into a lead compound. With this value determined from experiment, the rest of the quantities involved can be found by the equations of operation given in Chapter II. For one ampere-hour the results will be:

Spongy lead, at the negative plate	3.87 g.
Peroxide of lead, at the positive plate	4.47 g.
Sulphuric acid, at both plates together	3.67 g.
Corresponding quantity of sulphuric acid in a sufficient quantity of water to give the minimum of 1.15 specific gravity, *i.e.*, about a 20 per cent mixture, — the theoretical amount for filling the cell	18.35 g.
which produces of lead sulphate on both plates together	11.33 g.

In actual cells there must be electrical connection with these active materials, involving also their mechanical supports in the form of grids or plates, and if the real weight is not more than eight times the above theoretical values, the cells would be rather unusual. Heavier ones are ordinarily made, and preferred.

The rate of discharge of a cell is also a factor that concerns the efficiency, this appearing on the score of the resistance and polarization of the electrolyte. It is readily seen that rapid rates of discharge will impoverish the sulphuric acid in the immediate vicinity of the active material, and in the absence of sufficient causes for circulation, the weaker acid offers a higher ohmic resistance than normal. The result is a lower effective electromotive force at the terminals. During a rapid charge, too, more concentrated acid is produced near the active material, requiring a higher applied electro-

motive force for its overcoming. On the mere basis of ampere-hours, a battery may show a return of 8 or 9 for every 10 put in, but if the extremes of potential are counted, *i.e.*, 2.4 to 2.5 volts per cell during charge, and 1.8 volts during the last part of the discharge, the real efficiency will be as low as $\frac{1.8}{2.5}$ of $\frac{8}{10} = 60$ per cent, or less.

Just why a cell should require 2.5 volts during charge, yet during discharge give only 2 volts, is not explicable on the ground of ohmic resistance alone. Immediately after the close of a long charge, the voltmeter may show 2.4 volts, but in a few minutes, or at most, half an hour, the potential falls to about 2 volts, and during the discharge remains at that point for a long time, then slowly approaches the 1.8-volt mark, and should not be discharged lower. The explanation is, however, simple. The 2.4 volts corresponds to the condition when the plates are laden with gases, the positive with oxygen, the negative with hydrogen. Upon waiting a little while, these gases are disengaged, or upon closing the circuit they are at once utilized, the abnormal condition ceases, and the regular electromotive force between lead and lead peroxide, 2 volts, is left.

Another cause militating against a high average working efficiency, but tending toward reliability of operation, is the practice of regular overcharging. In small plants such as might be found in telephone exchanges, the overchargings may be practiced as often as once a week. From open cells there is considerable loss of water due

to evaporation and decomposition, requiring daily renewing. Also, during the charge there is some spraying of the electrolyte, which means a loss of acid as well as of water; direct replacing of the acid, however, may not be made oftener than once or twice a year, yet the specific gravity is still maintained at its required daily level. From reference again to Chapter II, it will be seen that during the charge sulphuric acid was formed, and of course, by keeping up the charge sufficiently long, the hydrometer can be brought to indicate the desired density. The energy expended in this manner is clearly chargeable against the operating efficiency of the installation.

With these various factors summed, and taking into the account the long range of discharge at the normal 2-volt point, the real efficiency of a good battery should not fall much below 75 per cent, — a value that gives some hope of improvement, but already far in excess of any other means of storing power.

CHAPTER XII

OTHER TYPES OF STORAGE BATTERIES

THOUGH the range of available materials is extremely limited, storage of electrical energy can be accomplished in some other ways than by the lead-lead-acid cell. A few promising constructions have been developed and exploited with remarkable perseverance and energy. From one cause or another, or from many causes, they have, so far, resulted in commercial failures, leaving, at present, the lead cell without a competitor. It may be well to indicate briefly what are some of the peculiarities of two of the most discussed forms.

The one consists of a lead positive and zinc negative in a solution of dilute sulphuric acid. During the charge, sulphate of lead is formed, and zinc is deposited; during the discharge, sulphate of zinc is formed and lead is deposited. Cells of this construction seem to have been made in small sizes only, and intended for replacing ordinary dry cells or those of the Leclanché and gravity type. As in the case of any acid primary cell, the zincs require amalgamation with mercury, and this protection from local action is effective only in case pure zinc is employed. A common size was made in a jar 3 in. diameter, 5 in. high, the whole weighing about

2 lbs.; it was rated as having a capacity of 10 ampere-hours, a normal rate of discharge of .5 ampere, and a maximum rate of 1 ampere.

A peculiarity of this type of cell is that its electromotive force has a working value in excess of that of the lead cell, being 2.5 volts on open circuit, and 2.35 volts when discharging at the normal rate. Though extensively advertised a few years ago by the United States Storage Battery Company, small mention seems now to be made of it.

The other construction, known abroad as the "Jungner," has, in this country, received considerable publicity from its connection with Edison. The European form was rather rudimentary. Edison sought to remove the objectionable features and to ensure the operation of the essentials. Instead of thick grids, the plates are of thin sheet steel, perforated with numerous small pockets, positives being filled with finely divided iron, the negatives with peroxide of nickel, the electrolyte a 20 per cent solution of caustic potash. One particular size of cell for automobile use is reported to have consisted of 14 positives and 14 negatives, the electromotive force 1.33 volts, and the internal resistance .0013 ohm, and the output 11.8 watt hours per pound of total weight.

While the alkaline solution has a conductivity relatively less than that of acid, the low internal resistance of the cell is obtained by virtue of the closeness with which the plates are stacked. Steel is inherently so rigid as to minimize the dangers of short-circuiting.

When the possibilities of this type of cell were first announced, the question was seriously asked if the days of the heavy and troublesome lead cell were numbered. With hesitancy shown by intending purchasers, the manufacturers of the standard batteries had no little difficulty in reassuring their customers as to the unsurpassable good features of their types. Still, some notable results were accomplished with the new cells, and when the public had reason to believe that the regular selling would actually begin, they were suddenly withdrawn from the market. In just what particular details they were not satisfactory was not then announced. Now it appears that it was Edison's intention to make the cells so rugged that they could be not merely sealed up, but with covers actually welded on, whereby repairs would be fairly impossible. Certain tendencies of the active material to become distorted by expansion and contraction had then imperatively to be examined and remedied.

The inventor, in 1910, has just announced the final perfection of the construction of the cell, and a full description of the details is given in another chapter. No attempt is here made to compare the relative merits of the two inherently different sorts of cells, — the lead and the nickel-iron, — it being recognized that first cost and weight are not the only considerations, but reliability, maintenance, and full-life efficiency are of higher importance.

It is important to observe that the new type of bat-

tery is specially designed for application to automobiles and street cars and that for the present, at least, no attempt is to be made to develop large stationary sizes demanded for central and sub-station engineering.

CHAPTER XIII

COMMERCIAL MAKES OF STORAGE BATTERIES

SUCH unanimity has been reached as to the efficiency and reliability of operation of the lead cells, that with the leveling effects of competition and absence of protection of patents, certain standard constructions have been adopted, and possessing, to the uninitated, a considerable degree of sameness. However, perfection often consists in attention to details, and no two persons necessarily solve a given problem in the same manner.

A description of some of the products of the largest manufacturers in this country, as far as possible, in their own words, will bring out the various peculiarities in the best manner.

As might be expected, each class of service demands distinctive constructions, and batteries for meager currents for laboratory calibrations, for portable or vehicle use, for residential or central station lighting, will differ very largely in size and appearance. Though each manufacturer complies with all these demands, the few pages allowable in this book cannot be expected to illustrate more than a few styles for which the cuts are available.

The Electric Storage Battery Company seems now completely to have abandoned its "Chloride" process in the manufacture of plates. This process consisted in the combination, in an early stage of the work, of a mixture of the chlorides of lead and zinc; then by the elimination of the latter, a final mass of very porous lead was obtained. Positive plates formed by the Planté method were found to be more satisfactory, but for a number of years longer the chloride process was retained for the negatives. Then negatives of the smaller sizes were made after the original Bradbury-Stone pattern, with a lattice-work grid. Instead of employing square openings in the castings, however, quite narrow rectangular ones were used, as being less liable to allow the dislocation of the active material. The negatives of larger size have a still different construction. The active material is confined between two sheets of finely perforated lead, securely burned together, and provided with various internal strengthening ribs. This type, shown in Fig. 28, is called the "Box Negative." The positives are known as the "Manchester" type. They consist of castings of antimonious lead, the grids being pierced with numerous holes nearly an inch in diameter. Into these holes are forced by hydraulic pressure little coils or spirals of corrugated lead ribbon. As the metal changes to the peroxide during formation, more space is occupied, and the pressure thus produced still further tightens the spirals in place, maintaining a state of compression which insures electrical contact with the grid. (See Fig. 29.)

Though representing various constructions, the name "Chloride Accumulator" is still retained as a trade-mark, as shown on the cell given in Fig. 30.

For especially light weight batteries for vehicular and other portable work, a special type, known as the

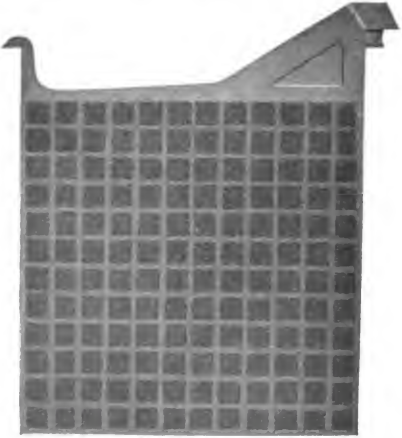


FIG. 28. — "Box-Negative" Construction
Electric Storage Battery Co.

"Exide," is made. In this, both positive and negative plates are in the form of pasted grids, consisting of double plates with numerous fine perforations; crosswise stiffening ribs preserve the shape, and the space between the plates contains the active material. Some negatives are

also made after the pattern of the Correns grid, but with the pellets long and narrow, rather than square.

The GOULD plate is of the Planté type, in the manufacture of which the "spinning" principle is used,

FIG. 29. — "Manchester" Positive, Electric Storage Battery Co.

giving the greatest obtainable "increased surface" and possibilities of modification of form.

Sheet lead blanks placed in steel frames reciprocate between two rapidly revolving shafts on which are mounted alternating steel discs and spacing washers. On the gauge of the spinning disc depends the width of

the groove and on the gauge of the washer the width of the rib.

A uniform pressure is maintained by the spinning rolls

FIG. 30. — "Chloride" Accumulator in Glass Jar.

against the face of the sheet lead; ridges and grooves begin to appear on the surface soon after the operation is started, and the discs or circular knives progress further

and further into the lead, displacing it and spinning it up in the form of ribs into the spaces between the knives. No lead is removed, the blank is merely changed in form.

FIG. 31. — Longitudinal Section through "Gould" Plate.

The circular disc entering at each end of the section leaves an unspun portion which anchors each individual rib to the main cross-bar at both extremities, a very fine line or web remaining through the center of the plate.

FIG. 32.—Formed " Gould " Positive Plate."

At the junction of two sections the two half diamonds of unspun lead form cross-bars of solid conducting material traversing the width of the plate. (See Fig. 31.)

These stiffening and conducting ribs produce subdivisions or sections that are made to vary in number and appearance with the overall size of the plates, as seen in Figs. 32 and 33.

In general, the Gould type is denoted as following the "soft-lead" principle in distinction from the others

FIG. 33. — Formed "Gould" Negative Plate.

that contain antimony, or paste, or active material not integral with the grid. In deciding which sort of plates to specify in a given contract, the purchaser would need to consider the probable uses or abuses to which the battery would be subjected. It is undeniable that the soft-lead plates will carry enormous "peak" loads, but this ability is often discounted by the tendency towards buckling of the webs and shed-

ding of the active material. Another example of the soft-lead plate is the "Tudor," — of German design and a marvel of expert workmanship. It is also now one of the products of the Electric Storage Battery Company, and the "Chloride" cells are made for foreign trade by the German firm.

Fig. 34 shows a large storage cell for a current capacity of several thousand amperes. The tank is of wood impregnated with waterproof paint. A sheet lead lining is used with overhanging edges so that the drippings will fall clear of the woodwork. Panes of plate glass resting on wooden strips in the bottom extend slightly above the lining, and on these the battery plates are hung. Since in ordinary three-wire electric lighting systems the neutral is purposely grounded, and in railway power circuits one side is also grounded, it is important that other grounds be rigidly suppressed. To minimize leakage, the tanks are therefore set on porcelain insulators. Especially on railway systems, the battery attendants have reason to exert considerable personal caution in their inspection and care of the cells.

The NATIONAL storage batteries have a high reputation, and represent a combination of the Planté and Faure formations. The positives, Fig. 35, are made on an ingenious "unit" principle, by which local expansion is permitted without communicating the distortion to the plate as a whole. The electrical connection, however, is not impaired.

The two sides of the Unit are uniform, and the devel-

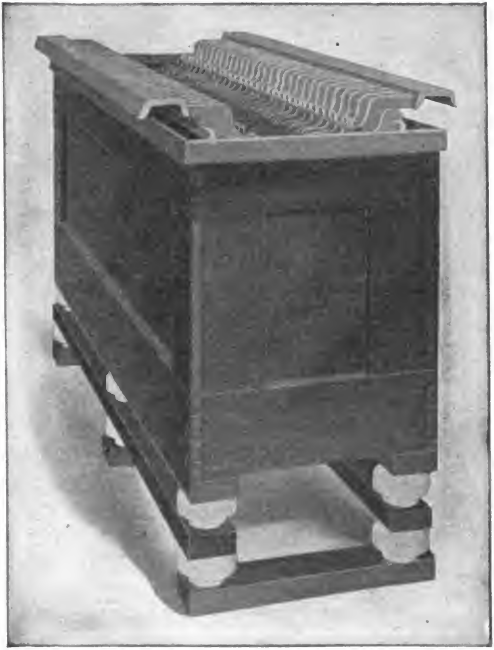


FIG. 34.—Large Storage Cell Complete in Wooden Tank.

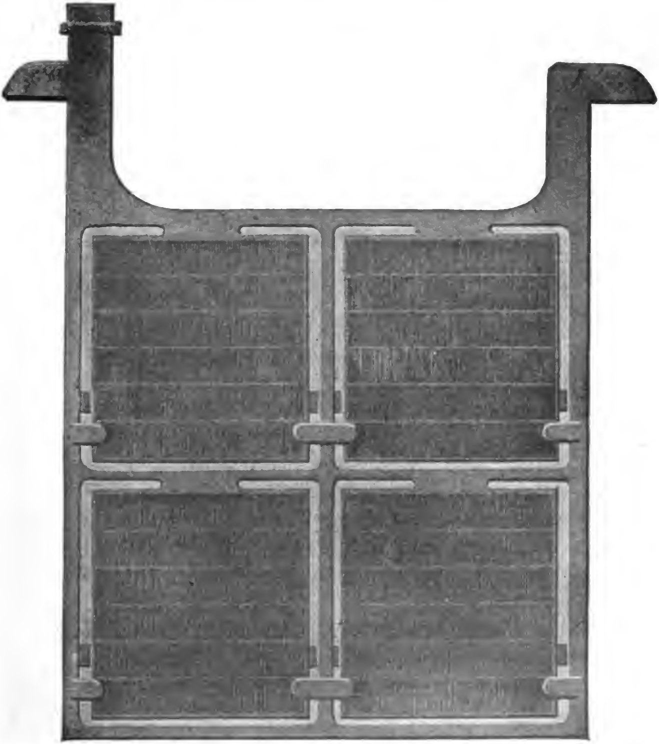


FIG. 35.—"Unit" Accumulator Positive Plate.

oped surface is sufficient to give high efficiency. In addition to this its mechanical structure is strong, holding the active material closely to it, and allowing free release of the gases.

Short circuits are usually due to form changes, which are buckling or bulging, and the falling off of the active material from the plates during service. The former results from the natural tendency of the positive plates to increase in volume, or "grow," causing an expansion of the active material portions of the plate. This is merely an additional formation of the active material, the development of which depends upon the nature of the service.

Experience has proved conclusively that it is impossible to prevent this growth, or Planté action, and most attempts have resulted in the distortion of the plates while in service to such an extent that they have to be removed at frequent intervals to be straightened. This is an expensive operation, which might be overlooked if one straightening were all that a plate required.

In the construction of the Unit Accumulator Positive, no attempt has been made to prevent this natural growth of the active material portions, but room has been provided to care for it. The Units, or active portions, are hung in a rigid lead frame, with ample space at the bottom and at the two sides of each Unit to allow for expansion, without in the least straining or distorting the supporting frame.

The National Battery Company have adopted the pasted type (Faure) of negative, and have developed a

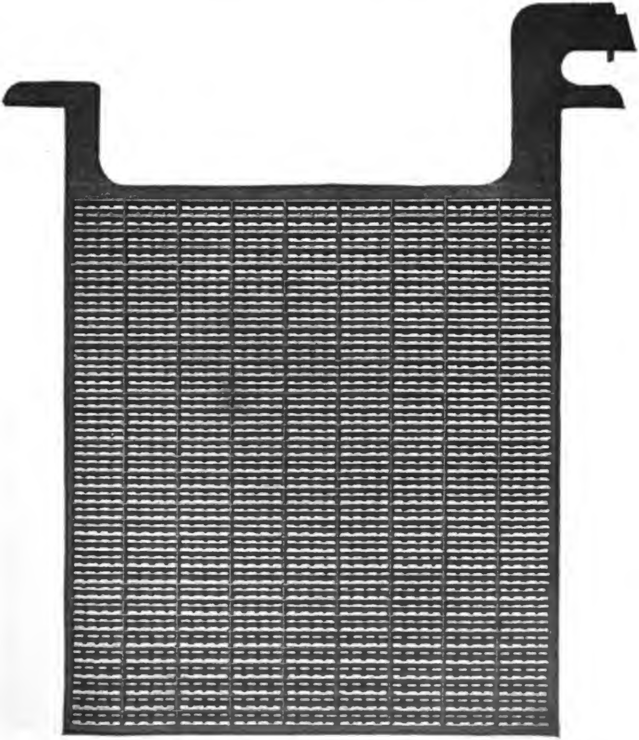


FIG. 36. — National Negative Plate.

grid in which the natural molecular shrinkage of the active material has been provided for and taken advantage of, so that the contact is maintained as the shrinkage progresses, owing to the fact that the active material enclosed in the contact portions is drawn more tightly around the grid projections or pins. A negative plate which loses its contact by shrinkage will cease to give its full capacity as this physical change takes place.

The Planté negative has been found to develop a high C. E. M. F. (back pressure) during charge, which does not occur with the National pasted type of plate.

In designing the Unit Accumulator, the objects sought, and believed by the makers to be attained, are the elimination of short circuits, the good and maintained contact between the active material and the grid throughout the life of the plates, and sufficient "active" surface to allow of high rates of charge and discharge, without mechanically weakening the active material portion of the plate.

THE WILLARD STORAGE BATTERY

The Willard Company is one of the oldest of the battery makers. It has installed and maintained successfully both large and small batteries, and has profited by a careful observance of their behavior. It has been conservative in maintaining those old features which experience has proven good, progressive in adopting those new ones which experience has not condemned, and now offers to the public its improved storage batteries with full confidence in their merit.

It will be noticed that the positive plate is sub-divided into small units by means of vertical slots and horizontal ribs. The individual units of the sub-divided plate retain all of the characteristics that have given the Willard

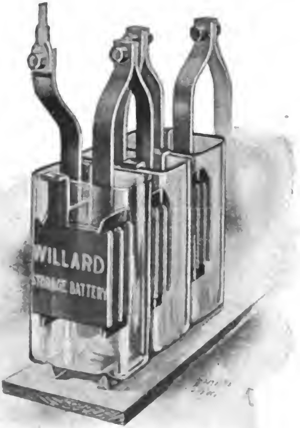


FIG. 37. — "Willard" Couples for Laboratory Uses.

Storage Battery its reputation for long life and high capacity. By sub-dividing the plate, the growth is taken care of, and buckling and bending are eliminated, as each little sub-divided unit acts independently of the others so far as growth is concerned.

The negative plate, not being liable to growth or distortion, is not sub-divided. By crossing the ribs at an angle on different sides of the plates, a plate of considerable rigidity has been obtained with a minimum amount of metallic lead.

Small stationary batteries, ordinarily installed in glass jars, must necessarily be of the highest quality. Not only do they receive less attention than the larger and costlier batteries, but usually their service is harder. Willard composition may be suggestive of the quality of their batteries. Knowing this, it has been the policy of the Willard Company in making these smaller batteries to give them the same careful attention that is given the larger batteries, and to make them not as cheap, but as good as possible.

All plates are made from single sheets of chemically pure rolled lead, electro-chemically formed.

Fig. 37 shows three small "couples" of the Willard type, such as are used for laboratory calibrations.

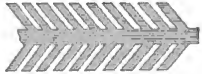


FIG. 38. — Cross Section through "American" Plate.

The AMERICAN Battery Company was the first manufacturer of storage cells to produce ribbed plates from rolled lead and form them electro-chemically, having had them on the market continuously since 1895.

The American storage battery plates are made from slabs cut from pure rolled sheet lead to desired size, the slabs or blanks being grooved, as shown in Fig. 38, leaving projecting ribs $\frac{1}{20}$ of an inch thick. These are made quite deep and then upset, thus allowing the use of plates having large surface exposed to the electrolyte, and at the same time affording, by reason of the ribs being upturned, a certain protection for the active material.

The latter is formed electro-chemically from the plate itself and is in direct union with it. The electrolyte has free access to every part of the plate, no asbestos or other diaphragm being used, and since the active material is in such close contact with the plate itself, the internal resistance is extremely low. The formation of peroxide of lead in the positive, and reduced or spongy lead in the negative plates, is by a special process rendered sufficiently porous so as to utilize with the least loss the reaction in the electrolyte occasioned by the charge and discharge.

Fig. 39 shows a set of "American" plates assembled ready for placing in the jar.

Notwithstanding the large area of plate exposed, sufficient support is provided to insure long life in constant and severe service. No greater capacity than three ampere-hours per pound of elements is sought for, while the weight is easily reduced by making the projecting ribs extremely thin; the latter will in ordinary work be converted prematurely into active material, which becoming detached from main or central support would

find its way to the bottom of the containing jar. The essential features of the American storage cell are large plate surface exposed to action of the electrolyte; adhered active material; ample leaden support; correct mechanical design in which allowance is made for all strains, buckling being therefore obviated; careful construction

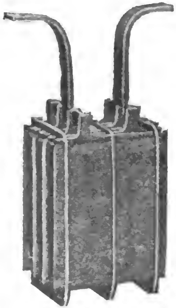


FIG. 39. — Small Size "American" Plates Assembled ready for Jar.

throughout, including lead burned terminals; terminals of generous proportions, and insulation which does not permit of the accumulation of sediment thereon. These render the American storage cells unsurpassed for all classes of service where the highest efficiency and greatest durability are required.

For the particular use of electric vehicles, specially light batteries of relatively large output have been designed. The pasted form of plates is usually em-

FIG. 40. — "Exide" Cell.

ployed for both positive and negative elements; they necessarily have to rest on their bottom edges, and have fairly close-fitting separators. These latter are both wood, to give porosity and space, and hard rubber, to give insulation even though the wood becomes

charred. Due to the small quantity of electrolyte, rather wider extremes of density are required than is desirable with stationary types of cells. It seems, however, like a rather short life for such expensive storehouses of power to admit that from 250 to 350

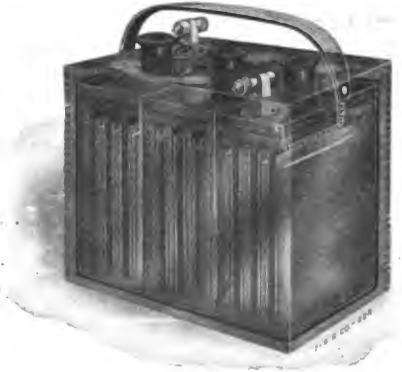


FIG. 41.—Phantom View of Sparking Battery.

complete discharges is the expected life of the positive plates.

The "Exide" is the familiar form of the Electric Storage Battery Company's make, and the National appears to be much the same. A view of the former, Type PV (power-vehicle), is given in Fig. 40. A phantom view of an igniter battery, using the same sort of plates, is given in Fig. 41.

The Edison Storage Battery Company, of Orange, N. J., announces the completion of the new cell, which is now being placed on the market. In outward appearance it does not differ except in minor details from the original cell, but the structure of the positive plate has been radically modified and other improvements embodied which greatly increase the capacity and durability.

The general make-up of the cell is clearly shown in the accompanying engravings, which, supplemented by the following brief description, should suffice to give a clear impression of the mechanical features of the Edison battery. At present the battery is made in two sizes; one size having four positive and five negative plates, and the other possessing six positive and seven negative plates. The active material in the positive plate consists of nickel oxide and iron oxide is used in the negative electrode. The electrolyte consists of potassium hydrate (21 per cent solution) to which has been added a small amount of lithium hydrate. The function of the lithium hydrate is not clearly defined, but it has been found to improve the working of the positive electrode. The normal specific gravity of the solution is 1.210, which does not change during charge or discharge. The efficiency and capacity of the cell, however, are not affected to any extent if the specific gravity of the solution is as low as 1.160. Below this a temporary effect is noticeable in the output of the cell.

The retaining cans are made of electroplated steel welded at the seams by the autogenous method — that is, by the application of the oxyacetylene blowpipe. The walls of the can are corrugated so as to obtain the greatest amount of strength with minimum weight. The iron element has an excess capacity over the nickel element, and does not differ from the iron electrode formerly used except that the process of making the active material and the method of loading it into the containers have been improved. Much time has been spent in perfecting the nickel element. The former positive plate was made up of flat rectangular pockets containing nickel oxide and graphite. It was found that the graphite oxidized and that mechanically the structure could not resist the swelling action of the nickel oxide. In the new plate round tubes 4 in. long and about the diameter of an ordinary pencil are used to retain the nickel oxide. The tube is made of thin perforated steel, which, when filled with the active material and properly bound by eight steel rings, makes expansion of the active material impossible and ensures perfect internal contact. Instead of the graphite formerly employed, electrochemically prepared flakes of pure nickel are interspersed in the oxide to increase the conductivity of the active mass, because nickel oxide of itself is a poor conductor. Each positive plate consists of a grid of nickel-plated steel holding 30 of these tubes. The negative plate comprises 24 flat rectangular pockets supported in

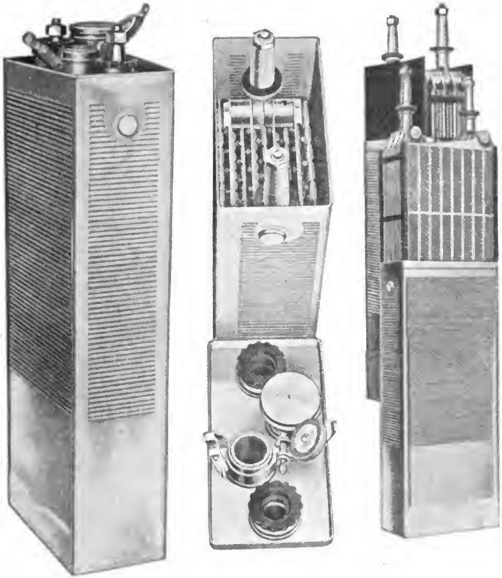


FIG. 42.—Edison Battery. Top View of Cell with Cover Removed. Cell with Electrodes Partly Lifted.

three horizontal rows in a nickel-plated grid. The pockets are made of thin nickel-plated steel perforated with fine holes, each pocket being filled with an oxide of iron and afterward subjected to very heavy pressure.

The plates of each group are hung on a connecting

rod perpendicular to, but integral with, the pole. They are held apart by nickel-plated steel washers and held firmly in contact by nuts screwed on both ends. The two outside plates are negative and are insulated from the retaining can by sheets of hard rubber. Hard-rubber pieces are also fixed between the can and the side and bottom edges of the plates, and these, together with the hard-rubber rods inserted between the plates, maintain correct spacing and ensure permanent insulation.

The cover of the cell, which is also welded in place, has four mountings. Two of these are for stuffing boxes through which the positive and negative poles extend; one is a separator which prevents the loss of electrolyte while allowing the gases to escape, and the other is an opening for water and electrolyte. This opening is fitted with a water-tight cap held in place by a catch. Fastened to the cap is a spring so arranged that the cap will fly open unless properly fastened. In an assembled battery each individual cell is held securely in place and from contact with adjacent cells by means of a small hard-rubber button which extends through the slat on each side of the tray and fits over an emboss pressed out on the side of the can. The bottoms of the cells are held in position by small buttons protruding from a conveniently arranged wooden block fastened to the bottom slats of the tray. The indentations in the bottom of the cell fit over these buttons. A rubber apron insulates the cell from the block.

The separator through which the gases escape while the battery is charging is designed in such a way that these escape in a substantially dry condition, the

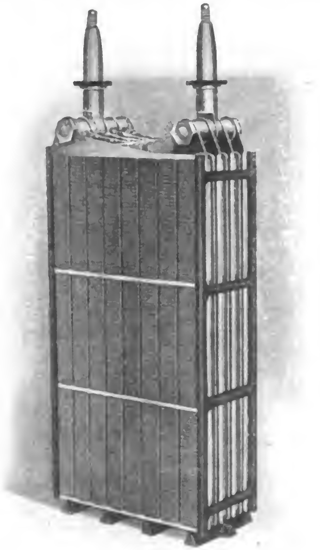


Fig. 43.—Assembled Plates of Edison Battery.

globules of liquid coalescing with a liquid film which forms at the base of the casing and seat of the ball valve with which the battery is fitted, and in this way

falling back into the cell. The electrolyte, therefore, need only be replenished with distilled water until completely changed every eight or ten months.

Electrical connection between the cells is made by means of heavy copper connectors, well plated with nickel. The lugs at the end fit over taper-joint binding posts and are held in place with a nut. A socket wrench for removing the nuts which hold down the connectors and a specially designed jack for lifting the lugs from the binding posts when disconnecting the cells are sent with each battery. The trays in which the cells are assembled are very light, and where formerly the ends and the bottom were dovetailed together, the trays are now made of continuous strips, the corners being bent. The data of the cells are given herewith:

	Type A-4	Type A-6
Rated ampere-hour output	150	225
Average discharge voltage per cell	1.2	1.2
Normal rates of charge and discharge in amperes	30	45
Weights (in pounds of cell complete)	13.5	19.2
Width of can	$2\frac{9}{16}$	$3\frac{3}{4}$
Breadth of can	5	5
Height of can	$13\frac{3}{8}$	$12\frac{3}{8}$
Height of cell to top of pole (not assembled)	$13\frac{3}{8}$	$13\frac{3}{8}$
Required height of battery compartment	15	15

While the normal rate of charge of the smaller cell, for instance, is 30 amperes, charging may be done at double this rate for a one-hour boost if the temperature is kept from rising much above 100° Fahr. It

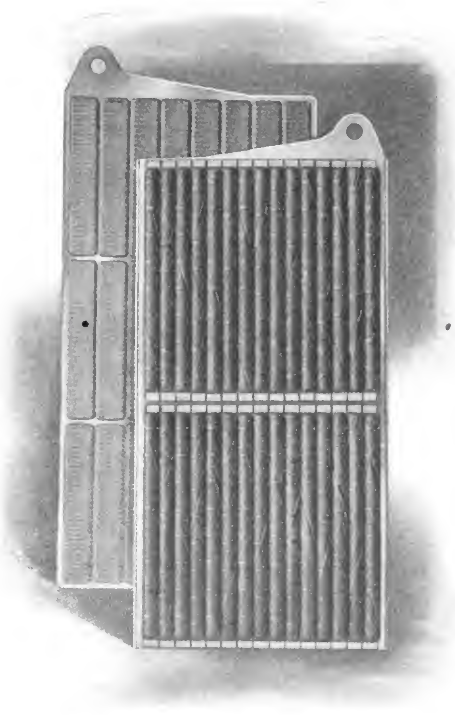


FIG. 44. — Negative and Positive Plates.

is also permissible, though not recommended, to discharge a battery continuously at rates up to 25 per cent above normal, and for occasional short intervals of time, as in hill climbing or starting on heavy roads, no harm is said to result if the rate be increased to three or four times normal. It will be seen from the accompanying curves that the capacity of the Edison battery increases after it has been placed in service, so that after working some time the efficiency is increased and greater output obtains also. This process of self-forming continues over a period of from one to three months of regular service and it is partly to assist in this forming up that the overcharges are recommended at intervals. The curves also show that the battery possesses reserve capacity. The highest practical limit of output is reached when a battery is charged ten hours at the normal rate, and its value will be, for a fully formed battery, perhaps 30 per cent more than the rated output. Efficiency is sacrificed somewhat, of course, when the highest available capacity of the battery is utilized. A seven-hour charge at normal rate is considered a normal charge.

It has been found in testing the battery under severe conditions that with a rated discharge three times normal the voltage drops 0.03 volt for every 10 amperes increase. On returning to normal discharge the voltage comes up to a value a trifle higher than normal owing to the heat generated at the heavy discharge rate. Heat on discharge increases the output while

heat on charge diminishes it; but excessive heating at all times impairs the life of the battery and should be avoided. The watt-hour efficiency of the cell is given in various curves and ranges from 60 per cent to 65 per cent. The smaller battery gives about 14 watt-hours per pound of cell, and the larger cell 16 watt-

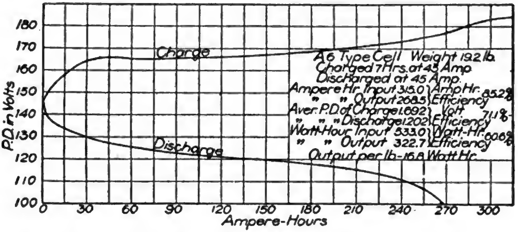


FIG. 45. — Characteristic Charge and Discharge Curves.

hours. The manufacturer lays stress on the claims that the battery cannot be injured by overcharging; it does not deteriorate when left discharged; any cell can be removed by simply detaching the connections from the poles, and the battery has nearly twice the output or mileage of other batteries weight for weight. The purity of the chemicals used and the structure of the cell ensure great durability and long life.

CHAPTER XIV

TYPICAL STORAGE BATTERY INSTALLATIONS

THE beneficial effect of storage batteries "floating" on a line is well illustrated by an installation for a certain street railway company. A straight-away distance of $7\frac{1}{2}$ miles was to be covered, and with the potential normally kept at 500 volts at the power house, a minimum of not less than 400 volts at the end of the feeder was to be allowed. Without the use of batteries a maximum current of 350 amperes would need to have been transmitted, with a loss in the track of 78 volts, and a line loss of 72 volts. The copper feeders would have weighed 300,000 lbs. By the help of the batteries, the cars were actually moved with a maximum line current of only 167 amperes, the track loss being 37 and the line loss 113 volts. Only 130,000 lbs. of copper was used. It was figured that the installation represented a saving of $22,000 in first cost and $1100 in annual operating expenses. A relatively high line loss in voltage is always needed in equipments of this sort, when batteries are located at the end of a long feeder, or proper conditions of charge and discharge will not be met; with no cars running, the voltage will be high

enough to send a charging current into the battery, but when a large demand for current is made, the potential falls sufficiently to allow it to discharge.

A battery thus connected makes no pretence of keeping the voltage constant, but at a reasonably average value. It reduces the amount of copper necessary for the transmission, and by taking the fluctuations of load that would otherwise fall on the power house, reduces

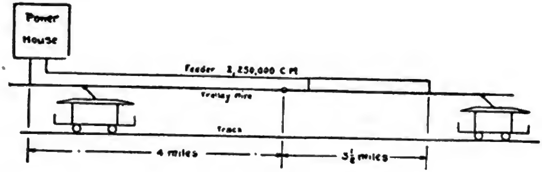


FIG. 46.

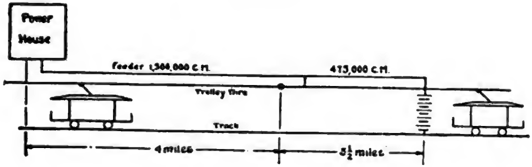


FIG. 47.

the amount of generating machinery required. Figures 46 and 47 diagrammatically represent the conditions without and with the battery.

For electric lighting purposes the voltage must be kept constant with the greatest nicety, and it is certain

that this condition can never be realized when dynamos directly feed into the line. So many causes produce momentary fluctuations of speed that the adjunct of the storage battery is needed for constant remedy. In this sense, storage is not the only consideration sought, but regulation. Customers of electric lights are more than ever insistent upon steadiness, and with the sharp competition felt from the increasing popularity of the Welsbach gas mantle, electric lighting companies have been urged to increasing activity to perfect their distribution systems.

One of the most valuable features of the storage battery system is its ability to maintain an even pressure on the bus bars to which it may be connected. Even though the load may vary greatly and the demands be very sudden, such as are occasioned by the starting of direct connected electric elevators and other heavy motor work, the battery will maintain a fairly even pressure at the bus bars of the station. It does this automatically and without any effort whatever on the part of the switchboard attendant. The medium sized station often finds this one feature of the storage system fully as important to it, if not more so, than the feature usually considered by the larger stations, that is, the ability of the battery to carry enormous "peak" loads of comparatively short duration.

Properly installed batteries often give remarkably satisfactory service, and sometimes show unexpected favors, as the manager of a station in a Western city

found. He states, "Another way in which our battery has proved itself useful and has made a direct saving of fuel and labor, is by taking care of the sudden loads thrown on the station by thunder storms which are so prevalent in this part of the country during the summer months. Before the battery was installed it was common practice to run more boiler capacity than would have been required had it not been for the sudden jumps in the load caused by a passing thunder cloud, and even then it was frequently necessary to raise steam in another boiler in short order, using boxes, barrels, or anything that would burn quickly, and then, perhaps, after only a few minutes' use, have to let the boiler cool off again, thus losing a large per cent of the heat units stored in that boiler."

This particular installation consisted of 150 cells of 2400 ampere-hours rating, connected on an ordinary 3-wire system. Figure 48 shows the cells as arranged in double rows, extending the entire length of a basement. The vertical bars seen at the distance end are the copper connections to the end-cells. Figure 49 shows the end-cell switches and motor-driven boosters. The switches have horizontally sliding contacts operated by small motors controlled from the switchboard. Two such switches are always needed to control the two sides of a 3-wire system, but in this case each set is double, whereby two different potentials are supplied, the higher feeding the more remote parts of the system.

A view of storage batteries as installed in a very large

central station is shown in Figure 50. A discharge current of nearly 10,000 amperes is allowable. An idea of the provision for conducting such currents is gathered from the quadruple copper connections shown on the terminal cell. Such heavy cells require special

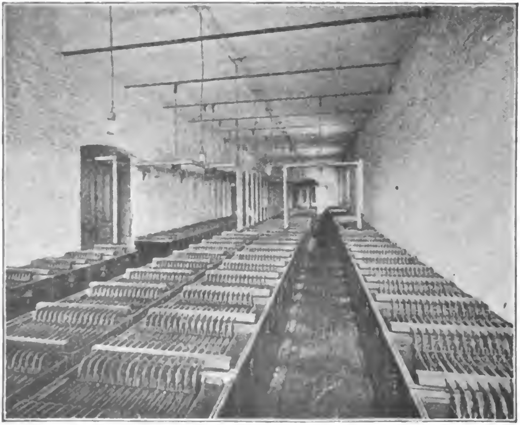


FIG. 48. — Battery Room in Central Station.

foundations, and being necessarily located in basements, artificial ventilation must be provided. Especially during the last portion of the charging process, when hydrogen gas is being freely evolved, must the gas be removed by exhaust fans, and fresh air admitted. Figure

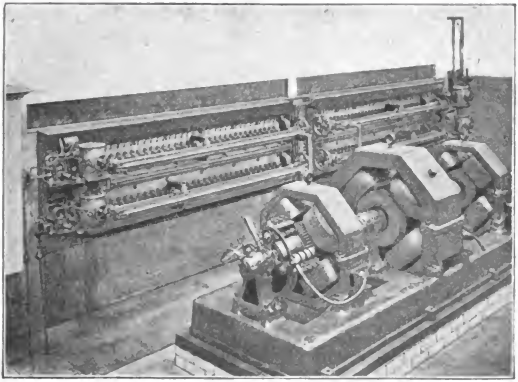


FIG. 49. — Boosters and End-Cell Switches.

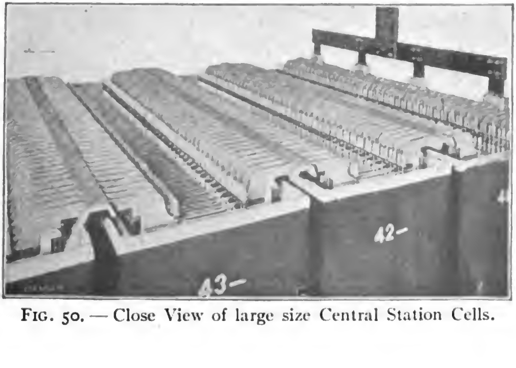


FIG. 50. — Close View of large size Central Station Cells.

51 shows a ventilated room and another view of these same large cells.

Storage batteries may be used in connection with transformers and rotary convertors at the receiving end of a long distance transmission. Switchboard and booster of such an installation are seen in Figure 52. Especially noticeable is the size of the copper cables and contacts of the armature and series coil circuits of

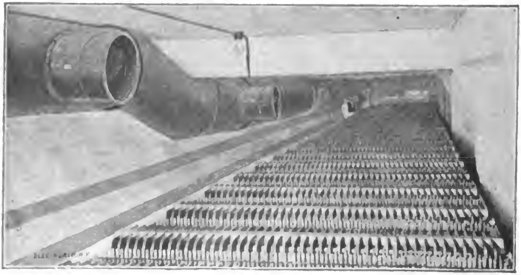


FIG. 51. — Tier of Cells — Ventilating System.

the booster. The regulating effect of the battery is seen by reference to the two cuts, Figures 53 and 54. These were taken from photographs and show that with the battery connected the variations lie between a minimum of about 113 volts, and a maximum of 118, as compared with 107 and 122, respectively, when the battery was off. In this particular installation, the addition of the battery at once made practicable the

running of incandescent and arc lamps, street car and other motors from the same transmission line.

While a storage battery should not be installed until proof of its probable value has been demonstrated by a careful study of the particular conditions, even a small station can often find it of advantage. A good illustration is given by the instance of a privately owned light-

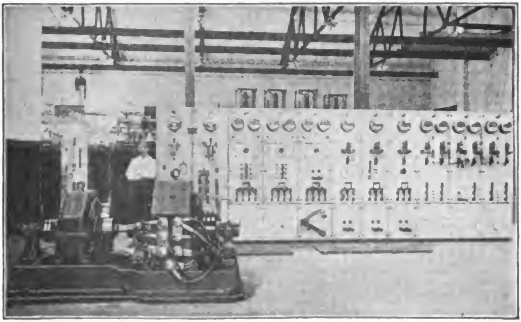


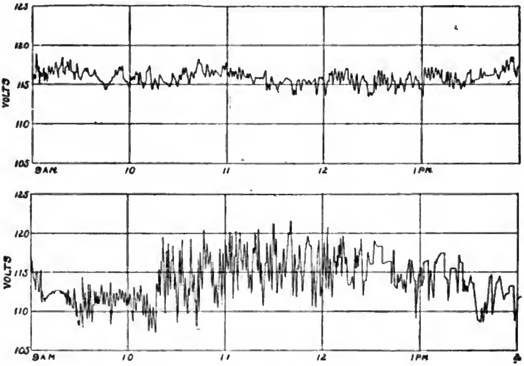
FIG. 52. — Switchboard and Battery Booster.

ing plant in a Western town, run in connection with a mill and machine shop.

Two 125 volt generators, one of 20-k.w. and one of 25-k.w. capacity, are run in combination, one on each side of an Edison 3-wire system, with 220 volts between the outside wires and 110 volts between the neutral and each outer wire.

Previous to installing the battery the center of load

was located within 100 yards of the plant, and the longest feeder did not at that time extend more than 100 yards beyond said center. Curve 1 (dotted line, Fig. 55), shows the load carried by the plant at that time. It will be noted that the maximum load of 150 amperes



FIGS. 53-54. — Voltage Curves, with and without Battery in Circuit.

was then reached at about 6.30 in the evening, and continued from that time until about 8.00 P.M., after which time it gradually decreased until 11.00 P.M., when it amounted to only ten amperes, remaining practically constant at that load until 12.00 o'clock midnight, when the plant was shut down.

At that time current was used for lighting purposes

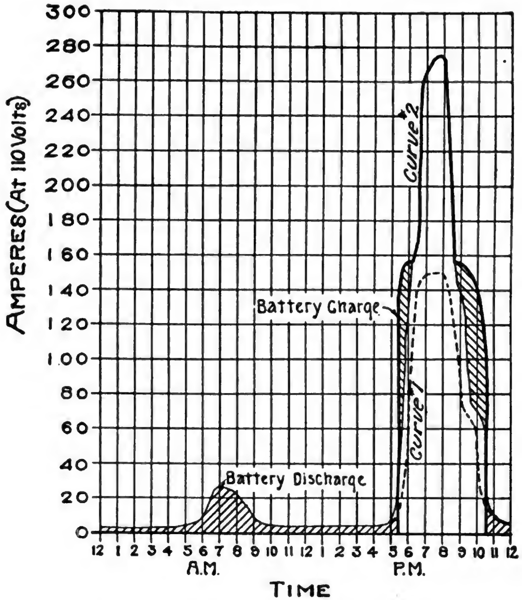


FIG. 55. — Load Curves of Small Isolated Curves.

solely, and that only by store-keepers; no electric motors then being used or electric lights in residences or on streets. The village Council had however, for some time previous, been agitating the question of street lighting, and had decided that if possible at reasonable

cost, this lighting should be done by electricity. Since, however, lighting mains were then distributed over such a limited area, while the street lighting contemplated covered a much more extended one, it was realized by the owner of the electric plant that provision for street lighting would entail an expenditure for copper, poles, etc., such as was not warranted by the returns offered from street lighting alone, but he found that if electric lights were also used in a reasonable number of residences located along the lines contemplated for street lighting, the additional investment required could probably be made profitable. The residence lighting, however, he found could not be obtained if current was furnished during evenings only, but he was assured that if twenty-four hour service was furnished, a liberal use of electric light in residences would be made, as from such a service they could obtain early morning lighting, and, during the hot summer days, run electric fans; the storekeepers also agreeing to use more electric current under these conditions, as they could then safely and at little expense have lights in dark rooms during the daytime, and when necessary in other parts of their stores during dark days. In fact, the great benefits to be derived from a twenty-four hour service were apparent to all, and the owner of the plant was strongly urged to provide same, and promised new business if he would do so.

After a careful study of the conditions and a thorough investigation of the different methods of meeting same, as well as providing for future requirements, it was

decided to install a storage battery to carry the late night and day load and thus provide for the maintaining of a twenty-four hour service.

This battery consists of fifty-six elements in glass jars, with a total capacity of 30 kilowatt-hours at the eight-hour rate of discharge. It is located as shown by Fig. 56 on a three-tier rack in a room 8 ft. x 12 ft. x 10 ft. high adjoining the dynamo room in the mill. As the battery is only required for discharging at light loads, the two outer wires of the three-wire system are arranged so as to be connected together at such time, thus converting the system while fed by the battery into a two-wire system, and as the load at such times is comparatively light, the drop in the lines is then less than on the three-wire system at times of full load. It is however planned that when the load increases sufficiently to warrant an increase in battery investment, a second similiar battery will be installed, and thereafter one battery used on each side of the three-wire system, thus doing away entirely with the necessity for converting the system from the three-wire into a two-wire one for any portion of the day or night.

The system of wiring mains was extended by running feeders in several directions a distance of two-thirds of a mile from the station, and a contract was entered into with the village under which enclosed arc lights were furnished for street lighting. In addition a large number of residences were equipped with electric lights in place of the oil lamps formerly used, and some ventila-

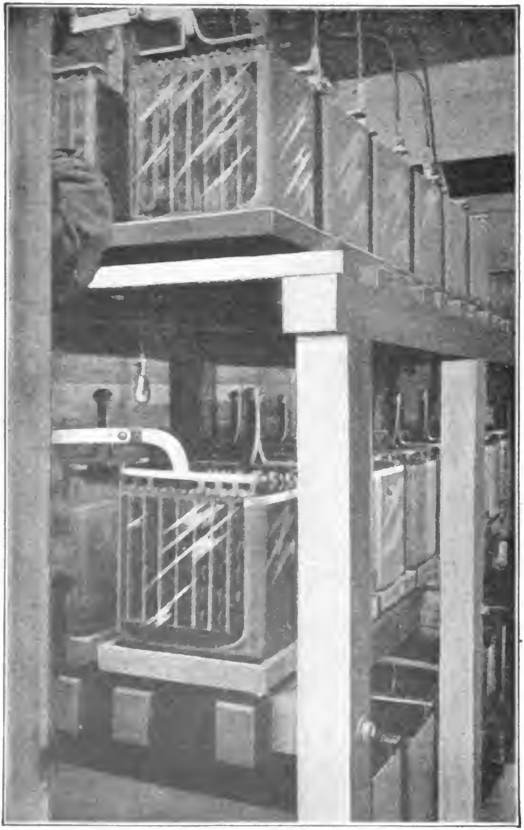


FIG. 56. — 3-Tier Arrangement of Storage Battery, with End-cells on top Row.

ting fan motors were installed in a school and in stores. The total increase of load at the station on account of the additional service amounted to the equivalent of the full load previously carried, as can be noted by comparison between the dotted curve in Fig. 55, showing the former winter load, and the solid curve which shows the load after the battery was installed. Left-hand cross-hatching, it will be noted, represents battery discharge, and right-hand cross-hatching, battery charge.

The time and amount of battery charge and discharge and hours of operation of the machinery are also shown by curve 40, these being according to the usual method of operation of this plant, as the generators are started each evening at dusk; one generator being connected directly to the battery for charging it, and the other furnishing the current required for the system, to which it is connected on the simple two-wire plan. When the lighting load increases to about 150 amperes, the battery is disconnected from its charging generator and both machines are used to furnish power to the system, which is then operated on the three-wire plan, the battery being allowed to rest until after the peak of the evening load, when the lighting lead has decreased sufficiently again to permit converting the system from three-wire to two-wire. The current required on the system is then supplied from one generator, the other generator being again used to charge the battery until shutting-down time, which is generally about 10.00 P. M. From that time, it will be noted, the battery carries the entire load

until dusk the next evening, with the exception of occasional days when the day load is excessive, due to the use of ventilating fan motors or unusually heavy lighting load — on which days the generators are run for a short time to carry such load until it decreases to the normal amount. This, however, occurs but rarely, the battery being fully capable of taking care of all late night and ordinary day demands.

No definite records have been kept which show the effect on net profits resulting from the use of the battery, but it has been noted that the evening consumption of current is now two-thirds greater than it previously was, and the day load added is equivalent to about one-third more, thus doubling the total load, or in other words, the amount of business done before the battery was installed. The total fuel consumption, however, has only increased about 25 per cent, indicating that the cost of fuel per kilowatt hour of current delivered from the switchboard to the system has been decreased about 37½ per cent. This decrease is principally due to the fact that the engine while in operation is always under full load and works much more economically than before the battery was installed, and in consequence now operates less hours each evening, as while in operation it is utilized to nearly its full capacity; the surplus current generated while in operation being stored in the battery and, later, when machinery is shut down, used to operate the system.

An unexpected and temporary arrangement of bat-

teries was on wheels, as shown in Figures 57 and 58. Seven old pattern steam cars on a pleasure beach line were transformed into a portable sub-station, containing 248 cells. Each cell had 27 plates, the capacity being 1000 amperes for one hour, 500 amperes for three hours, or 250 amperes for seven hours. The battery was

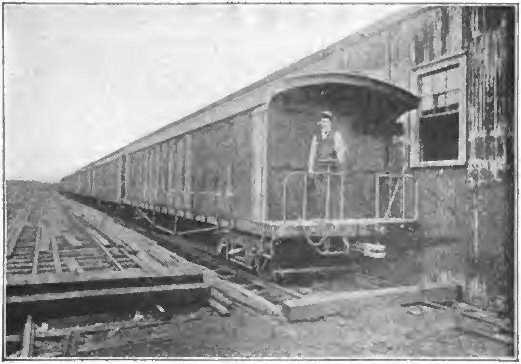


FIG. 57. — Train of Cars Containing Storage Battery.

charged through a special booster connected to one of the main feeders from the power station. It was of great importance to have this auxiliary power reserve, as the large trains that ran to this resort were heavily loaded, and required a great amount of current. Pending the erection of a permanent sub-station with rotary convertors, this expedient was adopted with gratifying

results. One of the cars was equipped with a switchboard and complete regulating apparatus. A competent attendant was always present to watch the operation of the battery and to secure its satisfactory performance. This was therefore not only a novel installation, but showed the value of storage batteries in

FIG. 58. — Interior of One of the Battery Cars.

furnishing power where the demand was only required for periods of heavy load, or during certain seasons of the year. When not in use at the beach the equipment was moved to the city to assist in carrying the winter load there.

A notable case in which storage batteries relieved

distressing and even dangerous operating conditions was in a railway power house on the Pacific coast. Only a few trains were running at any time, but these were of the regular steam type. If two trains started at the same instant, the demand for current was quite beyond the capacity of the two engines; the average load, however, was well within the reach of the smaller unit. Before the battery was installed it was often necessary for an attendant to stand at the throttle of each engine, and by hand, admit live steam to the low-pressure cylinders when otherwise the engines would have been stalled, and then a few moments later quickly to close these valves to prevent the engines from racing.

The trains operated on the road consist of four to eight cars, only half of them having motor equipments. One train each way every half-hour is the regular schedule. Power house is located about midway between the two termini, and at first contained one 840 k.w. and one 600 k.w. capacity generators. A storage battery of 550 k.w. capacity with booster and switchboard was then added. Figure 59 shows the latter. The road is now operated about 20 hours per day with conditions as follows:

The average week-day load is about 700 amperes as shown by the dotted line in the load diagram, Figure 60. The minimum load is about 160 amperes, and the maximum load about 2200 amperes, as shown on this diagram. The division of the load between the generators and battery is also shown on this curve, the inspection

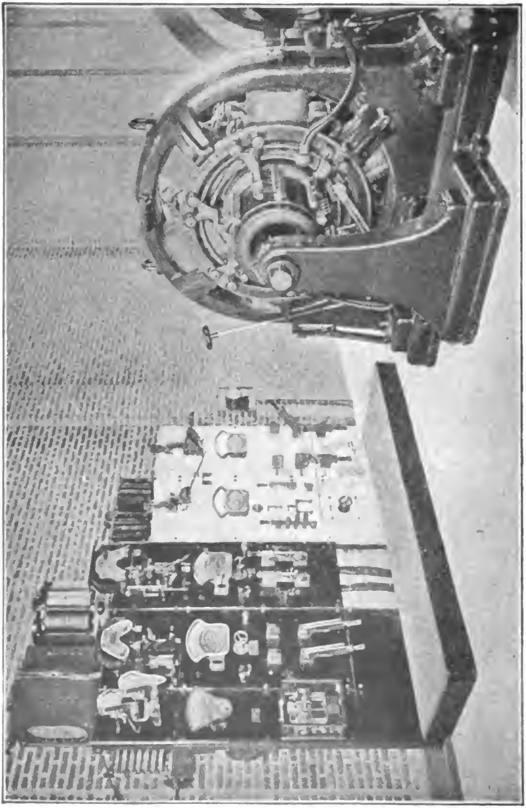


FIG. 59. — Booster and Switchboard for Suburban Railway.

of which will indicate a nearly constant load for the generator, the fluctuations being taken by the battery, which automatically operates from 1400 amperes discharge to 500 amperes charge. During morning and evening peaks, as well as holidays, the traffic demands an increase in the number of cars operated, with an increase in the average load to 1000 amperes, minimum being 400 amperes and the maximum 2800 amperes. The division of current is such that a nearly constant

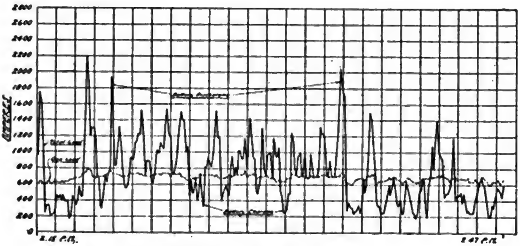


FIG. 60. — Load Curves.

load of about 1000 amperes is kept on the generator, while the battery automatically takes care of the fluctuations to the extent of 1700 amperes discharge and 600 amperes charge.

It is needless to dwell on the advantages resulting from the regulations of the fluctuations of load by the battery, as an inspection of the curve by any one familiar with station operation will bring forcibly to his mind the resulting economy of fuel consumption and decreased

cost of maintenance of engines, generators and boilers, with a corresponding decrease in attendance, as well as a large increase in capacity of output of the station.

It may be noted that the maximum loads are beyond the combined full load rating of both generators, while the operation of the battery makes it possible to handle the station load at any time with one machine.

Among the numerous applications to which storage batteries have been adapted, one of the more recent, and by no means least important, is its use in connection with the direct current exciters in alternating current power and lighting plants. The exciter, though a seemingly insignificant part of a large alternating current installation, is nevertheless a vital part, without which the entire plant becomes useless. To guard against even momentary interruptions of current in the exciter circuit, it is becoming standard practice to install a storage battery which shall at all times float on the exciter bus, ready to assume the load and maintain current in the fields of the alternators in case of any accident to the exciters. Such a battery also serves to supply field current in starting up the plant after a shut-down, where the exciters are driven by alternating current motors. It will also assist materially in reducing fluctuations of alternating current voltage which are often aggravated by corresponding fluctuations of exciter voltage and current if there is no battery to prevent.

The number of alternating current stations equipped with batteries for the exciter circuit is constantly in-

creasing. In some cases the battery was included as part of the original layout; in other cases the battery has been installed after experience has demonstrated the absolute necessity of such a safeguard; and it may safely be stated that no modern station of this character would be considered up to date in engineering details without such a battery on its exciter bus.

One of the largest city electric lighting companies has installed two exciter batteries. Twenty of the cells are used as end-cells and are connected to a 21-point motor-driven end-cell switch, located just outside of the battery room. The battery itself is installed in a small brick building adjoining the power house, and the cables and wiring for the control of the cell switch are brought to the switchboard gallery at the other end of the building. The battery is floating constantly on the exciter bus at 125 volts, from which bus current is supplied for the fields of the two 2850 k.w. alternators as well as for lights in the station and for the operation of the alternating current circuit breakers in the outgoing lines, these being opened by direct current by means of relays in the alternating current. There are two 150 k.w. exciters, each driven by a synchronous motor. These exciters have a range of voltage from 110 to 150, the higher voltage being used for giving the battery a full charge once or twice a week. In the main lead of each exciter is connected an underload circuit breaker which will open in case it should lose its load by a reduction of speed or field strength, thus preventing the battery from

discharging back through the machines. There is, however, no circuit breaker in the battery circuit and the battery must take whatever load happens to fall on it in an emergency. The current taken from the exciter bus varies from 800 to 1600 amperes at different times of the day; and if the exciters go out for any reason, this entire load will fail on the battery.

In case of prolonged interruption in the operation of the exciters, the falling off of battery voltage due to a continued heavy discharge may be counteracted by cutting in additional end-cells. Under ordinary conditions, however, interruptions are of such short duration that this is not found necessary.

This battery has been called upon a great many times to meet those emergencies for which it was installed, and on many other occasions it has served to prevent the exciters from going out by holding them up to speed until the disturbance, such as short circuit on the alternating current lines, should have passed. In this way the battery has been of inestimable assistance in preventing interruptions of service or severe fluctuations of voltage.

Operators of long distance transmission systems are especially confronted by the difficulty of protecting the great length of line between their water power stations and the centers of distribution. To meet this the construction of such a system is frequently supplemented by the erection of a steam auxiliary station in the city, so that interruptions caused by broken or short circuited

lines will be reduced. But this does not entirely solve the difficulty, as it is not possible to start up an engine and connect it on the system without a delay of fifteen or twenty minutes. In order to insure their customers continuous service, some companies have very successfully installed storage batteries.

One plant in the far West has a battery, consisting of 140 cells of 35 plates each; the tanks, however, are sufficiently large to contain 81 plates. This battery at present is capable of discharging 3500 amperes on each side of the three-wire system, but when all the plates are installed in the tanks the battery can be called upon for 9000 amperes per side. With this battery are installed six motor-driven end-cell switches, three on each side of the system. This arrangement permits great flexibility in handling the battery. For example, one cell switch may be utilized when charging the end-cells, while by means of another, the main battery may be connected to and kept floating on the bus. One of these cell switches may be utilized to maintain an auxiliary high pressure bus during such hours as the load on the longer feeders requires this; while for discharging at maximum rates, two or more cell switches may be operated in multiple. A view of the switchboard is given in Figure 61. It shows well the large capacity switches at the bottom, and the "tell-tales" for the location of the contacts on the end-cells.

The general adoption of the "common-battery" system in telephone exchanges in place of the magneto

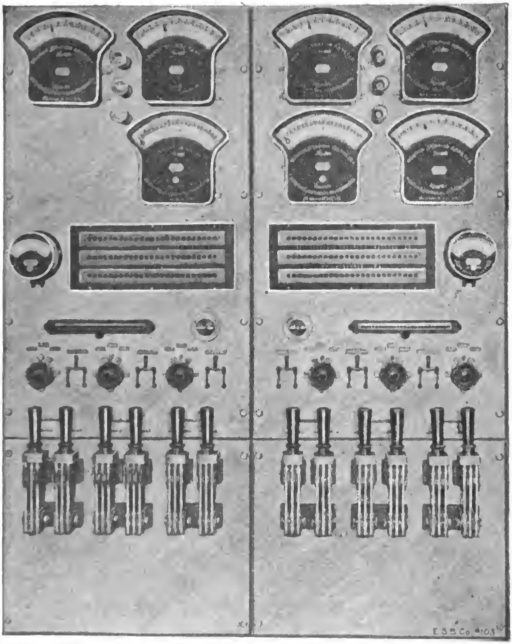


FIG. 61. — Switchboard for Three-wire System with three End-cell Switches on each side.

call-bells and local batteries is one in which the qualifications of storage batteries have been eminently set forth. The current must be free from fluctuations and

absolutely reliable. One of the first installations of this sort was in 1898, and its operation proved such a success as at once to encourage the general adoption of the system. A description of this pioneer plant is well worth repeating.

Situated in the engine room are two machines, forming a duplicate plant, each consisting of one engine, direct coupled to a 30-k.w. 110 volt dynamo. These machines are run alternately every other day and are used for lighting the building and furnishing power at 110 volts to motor-generators in the power room on the sixth floor used for charging the storage batteries and furnishing ringing power to the telephone switchboard. The motor-generators have their primary ends connected to the 110-volt direct-current circuit fed from the generators in the basement.

These motor-generators comprise two 1500-watt machines for charging a 20-volt battery, one 1500-watt machine charging an 8-volt battery; one 500-watt machine charging a 4-volt battery, and two ¼-h.p. 75-volt alternating-current motor generators for ringing. Only one machine is furnished for the 8-volt and the 4-volt batteries, which are in duplicate. To avoid a possible breakdown, an enamel rheostat is furnished, so that the batteries of lower voltage can be charged from batteries or motor-generators of higher voltage. All machines are protected with automatic safety cut-outs.

The 20-volt battery consists of ten accumulators having a capacity of about 1000 ampere hours, which fur-

nish all the current needed by the subscribers for talking and for calling up the office. The 8-volt batteries, in duplicate, each consists of four cells, having a capacity of 2400 ampere hours. This battery furnishes current for the "disconnect" signals on the operator's cords, and for the relays which cut out the subscriber's lamp signal when the operator answers his call by plugging into the jack corresponding to the lamp signal. The disconnect lamps are so wired that they burn only when the subscribers connected by the cord need attention from the operator. They do not light while the subscribers are talking.

Half the drop in potential of the 8-volt battery is in the 4-volt lamp, and the other half in the cut-out relay. This battery is in duplicate, so that one can be charged while the other is being discharged. This avoids danger of burning out the lamps, as the voltage of the battery is raised from 8 to 10 volts during charging. The 4-volt battery consists of six cells in duplicate. One of these sets consists of four cells, two in series, two in multiple; the other of two cells. The two extra cells are needed on one of the batteries to supply current for the operator's transmitters. This battery is arranged to furnish a current of four volts or two volts as desired. The 4-volt battery also furnishes all current for lighting the lamp signals which light when a subscriber takes his telephone off the hook. This lamp is put out when the operator answers the call as was described under the 8-volt battery. This battery is made in duplicate, one being

charged while the other is discharged, to avoid burning out the lamp from the higher voltage during charge.

The power switchboard and mounting fuseboard are constructed of white marble, mounted on an iron frame, and equipped with switches, measuring instruments, fuses, etc., for the necessary circuits.

The function of the battery is as follows: The subscriber by taking his telephone off the hook, operates a relay at the central office, which operates a 4-volt lamp in front of the operator at the switchboard; this lamp is extinguished as soon as the operator plugs into the jack. The cord with which the operator connects together the jack of the subscriber calling with that of the subscriber desired is wired to the 20-volt battery, which furnishes all the current used by the subscriber in talking. The automatic 4-volt lamp "disconnect" signals on the operator's cords are operated in the manner already described. Fig. 62 shows arrangement of battery and switchboard.

Among the refinements of modern railway travel, none is more appreciated by the traveler than the application of electricity to train lighting. Electric lighting of cars is so far superior to other methods that its use has now become standard for high-class trains, and the time is approaching when its use in all passenger trains will become standard.

Advantages of electric train lighting are:

Freedom from danger of fire in case of accident. Brilliancy and steadiness of the lights. The lighting

may be divided into small units and placed wherever desired. It is the only method permitting the use of lights in the berths. It has no odor and does not vitiate the air. It gives off a minimum amount of heat. The power may be used to drive fans for cooling and ventilating the cars.

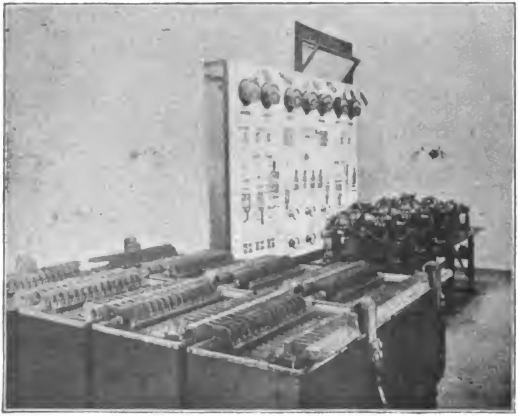


FIG. 62. — Generating and Storage Battery Plant in a Telephone Exchange.

The storage battery is necessary for continuity and reliability of service in all methods of electric train lighting, of which there are three general divisions:

First. — A battery under each car, charged from an outside source at the end of each run. *Second.* —A

battery and axle-driven dynamo on each car. The battery is connected across the lighting circuit is parallel with generator, charging when the load is light, discharging to assist the generator when the load is heavy, and carrying the entire load when the train speed falls below a certain minimum or when train has stopped.

FIG. 63.— Dining Car with Storage Battery Lighting System.

Third. — A steam-driven generating unit in the baggage car or on the engine, with a battery on each car. The battery may float across the lighting circuit, taking the entire load when the generator shuts down or the car is uncoupled; or may be a reserve battery, thrown across the lights either by hand or automatically when the dynamo is not running.

The operating and maintenance cost of the batteries, which were rather high in the earlier days of electric

train lighting, have been very greatly reduced. These high costs were due partly to the apparatus not being sufficiently developed for this service and partly to lack of experience in its care. A dining car equipped with storage batteries for electric lights is shown in Fig. 63.

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